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THE EXISTENCE AND FUNCTION OF INNER SPEECH IN THOUGHT PROCESSES

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The purpose of this experiment was to discover the functions of inner speech in the thought processes, particularly in the apprehension of meaning in reading. That is, Is inner speech an important aid either in the apprehension of meaning or as a vehicle of thought, or is it merely an incidental by-product of these processes? A considerable literature has been produced upon this subject but it is mostly introspective in character, very little having the stamp of objective certainty. By way of introduction it will be helpful to refer to two important papers that were among the first to appear upon the subject, those by Dr. S. S. Stricker and M. Paulham.[1]

In a small monograph, which appeared in 1880, Dr. Stricker, reporting principally his own introspections, says that he cannot call up images of any sort without making incipient speech movements corresponding to their verbal symbols. For example, he cannot imagine the sound of B without an incipient feeling in his lips nor think a tune without incipient singing movements in his larynx. He says he cannot understand any words without reproducing them in inner speech or think of father and mother at the same time because the accompanying speech movements must be made successively. After a long practice period he, however, learned to read a newspaper while repeating aloud a ballad of

[1] For other literature on the subject see Pintner, *Inner speech during silent reading*, Psych. Rev., 22, 1913, 129f; and Wyczoikowski, idem, 326f.

Schiller, but in this case, he says the speech movements came in between the words of the ballad. Dr. Stricker tended to give his introspections objective value by questioning a hundred persons in regard to lip-feelings accompanying M, P, and B in silent thought, and found only one who did not experience them. He also questioned sixty persons in regard to inner speech accompanying silent reading and found only two who did not experience it.

In 1886 M. Paulham offered his own introspection in reply to those of Dr. Stricker. He said that he could sound the vowel A continuously and at the same time get images of all the other vowels. He can image the sound of any vowel without any motor accompaniment. Inner speech is an individual peculiarity. Thought may be represented by other forms of imagery, auditory, motor, visual, or even abstract representations which are unlike any sensible image. In fact, words may be understood without any images. All that is required is to prepare the proper reaction to which the word is a stimulus.

For Stricker inner speech is the indispensable vehicle of all thought; for Paulham it not only is useless but even does not exist. These two cases illustrate the confusion which results from the introspective method as well as the necessity of finding a method which will yield objective validity with reference to the phenomena in question.

To settle this confusion, experiments were begun with the view of getting objective evidence of the existence of inner speech. After devising several instruments for registering inner speech movements, I finally settled upon a speech receptor illustrated in Fig. 1, and believe it successfully registers speech movements when they occur. It registers only tongue movements, but it is very probable that tongue movements are made whenever speech movements of any sort occur. If this is the case, objective evidence of inner speech may be secured from registering tongue movements alone.

This instrument is made of a block of wood $5 \times 2 \times 1.5$ cm. in size, one end of which is cut in the form of a mortice

3 × 2 × .5 cm. To this block two thin steel wires in the form of *a b c d e f g* (Fig. 1) are fastened, over which is stretched a condom of very thin rubber. This is fastened airtightly to the cut end of the block by a wrapping of rubber sticking tape. The wires and condom form a drum which is sensitive to the slightest pressure. A hole drilled through the long way of the block admits a pipe stem to which a rubber tube from a writing tambour is attached, thus forming an air passage between the tambour and the speech receptor. The drum as thus constructed is put into the mouth cavity, which it fills, and is held in place by closing the lips and teeth upon the morticed end of the block. Breathing or movements by the tongue produce changes in air pressure which can be registered.

The records were taken on smoked paper rotated by a kymograph. First a record was taken of the breathing when the subject was told not to think of anything. Above this a so-called silent reading curve was taken while the subject read a brief newspaper clipping. This was continued by a so-called writing curve taken while the subject wrote a review of the clipping. Above the writing curve a so-called whispering curve was taken while the subject reread the clipping in a whisper. Sometimes a so-called reading-aloud curve was taken above the whispering curve for the same passage. The curves arranged in this way are easily compared. If, then, we find that the silent reading curve is like the breathing curve, it may be taken as evidence that the subject does not make speech movements in reading. If, however, it is like the whispering curve, then it may be taken as evidence of inner speech, for, by analogy, something similar to the whispering occurs.

Since the speech receptor records not only the tongue movements but also the changes in air pressure due to breathing, some means had to be found for separating these two elements. To do this I took breathing curves from three other places, the nose, the chest, and the abdomen. For the chest and abdomen pneumographs were used. For the nose I used a glass tube held in one nostril by means of a rubber

nipple. For the use of this instrument I am indebted to Professor Raymond Dodge, who suggested it. As illustrated in Fig. 2, one end of a small glass tube is pushed through the end of the nipple and is kept from slipping by wrapping the tube with rubber sticking tape underneath the nipple. The bulb of the nipple fits tightly into the opening of the nostril and holds the instrument firmly while in use. It does not interfere with breathing, since the subject has the free use of the other nostril. The other end of the glass tube allows a rubber tube connection with a writing tambour.

Each of these instruments was connected with its own writing tambour, the needles of which were sharpened in different ways so as to make the graphs distinguishable. The graphs, together with the time line, for which a Jacques chronograph was used, were all taken at the same time and in the order described above. The subject thus equipped with a speech receptor in his mouth, one pneumograph about his chest, another around his waist, a rubber nipple and glass tube in his nose sat comfortably at a table, read newspaper clippings silently, in whisper or aloud; wrote abstracts; counted mentally, in whisper or aloud; performed mental multiplication problems; or added columns of figures as directed by the experimenter. After each performance the subject's introspections were noted. These will be compared with the graphic records which we are now prepared to study in detail for each subject.

To begin with the curves secured from Mr. D. are very interesting. Record 1 shows the breathing (*B*), reading (*SR*), writing (*W*), and whispering (*Wh*) curves taken in connection with clipping No. 4. The breathing curve is at the bottom of the record. It is a series of regular hills and valleys. The steep slope of the hill is the graph for inhaling. The long slope may be analyzed into two steep slopes connected by a line relatively horizontal, which indicates not only that inhaling has a relatively longer duration than exhaling but is made up of two inhaling movements with a period of relative rest between them. Next to the breathing curve came the silent reading, the writing, and the whispering

curves in order from bottom to top. The silent reading curve not only indicates deeper and faster breathing but shows numerous irregularities in the form of sharp peaks all along the line. It is improbable that this subject breathed in such a jerky fashion. These numerous sharp peaks almost certainly indicate that the subject spoke the words silently to himself as he read the clipping. This becomes all the more evident when the silent reading and whispering curves are compared, the only difference appearing to be in the magnitude of the tongue movements. The likeness between the silent reading and whispering curves is still more striking in Record 2[1] for which the subject read one word per second to the beats of a metronome. This procedure evidently exaggerated the tongue movements. In Record 3 the silent reading (*SR*), the whispering (*Wh*), and the reading-aloud (*RA*) curves for the same passage together with the time line and breathing curves are shown. There is a very general similarity between the reading-aloud and the whispering curves, showing a corresponding similarity in speech movements. The silent reading shows much more similarity to the whispering and reading aloud curves than it does to the breathing curve. Surely some element quite foreign to breathing comes in here. Comparison of the curves indicates that it must be inner speech. However, not to be too hasty in coming to this conclusion I took the records of individual words for the same passage, a part of which is shown in Record 4, in which the subject read one word every other second to the beat of the metronome. In the reading aloud curve I made a dot at the completion of each word so as to make clear the amount of graph due to each word. I then wrote underneath each division the corresponding words. The silent reading curve was taken under the same temporal conditions. Guided by the amount read, the word order, the time order, and the almost identical form of particular graphs such as those for 'juryroom,' 'general sessions,' etc., I wrote out the words for the silent reading curve. There is no doubt in this case that the subject used inner speech in his silent reading and

[1] Records marked with a star are omitted.

that the speech movements were very similar to those made in reading aloud. If now we compare the silent reading curve of Record 4 with that of Record 3 for which the subject read normally we see that these are much more similar to each other and to the whispering and the reading-aloud curves than to the breathing curves. Undoubtedly the same cause explains the irregularities of both curves, that is, inner speech. Records 1, 2, 3 and 4 were taken with the speech receptor alone which registers the impressions from both the speech and the breathing processes. In Record 5 the breathing curves from the nose, chest and abdomen are shown in relation to the curve from the speech receptor. The breathing curves from the four receptors show about the same amount of regularity, the one from the mouth being slightly more varied than that from the nose and chest but no more than that from the abdomen. In the silent reading curves the breathing curves from the nose, chest, and abdomen are just as regular as in those below but the curve from the mouth is vastly different, having numerous peaks not contained in the other curves. If these peaks were due to breathing, they would appear in all the curves, for the air pressure within the nose, mouth, and lungs must be the same. In the whispering curves the breathing is more irregular than in silent reading, but the great peaks coming from the speech receptor are certainly not due to breathing, but to speech movements, which also account for the irregularities in the silent reading curve. With this I take it that the objective certainty of inner speech in silent reading and in writing in case of this subject is established.

After having tested my subjects for inner speech during silent reading and writing, I also took some graphs while the subjects performed mental multiplication problems; counted, mentally, aloud, and in whisper; and added columns of figures. In Record 6 a section of the graph for multiplying mentally 98×15 and 258×93 are shown. The graph marked *Wr* $\times$ 15 is the writing graph for the clipping used for Record 5. It shows inner speech very clearly. The graph for mental multiplication 98×15 shows inner speech

for that process. But the 258 × 93 shows very little inner speech. What is interesting here is that the breathing becomes fast and very short. In Record 7* the graphs from the speech receptor are shown for breathing, mental counting, counting in whisper and counting aloud. The subject counted from one to ten to the beat of a metronome. No inner speech appears in the mental counting. But the graph shows that the subject counted with his breath, there being five peaks for the ten counts, one count for each exhale and inhale.

Reporting his introspections Mr. D., whose records we have been studying, says that he pronounces the words to himself in silent reading and in writing. He thinks he sometimes whispers them halfway. In mental multiplication and in addition he repeats the figures over to himself. In fact all his thought processes are carried on in the form of inner speech. When I called his attention to the mental counting, he admitted that he did it with his breath. His introspections agree with the graphic records with the possible exception of difficult problems in mental multiplication.

The next subject to be studied is Mr. E., whose records are very different from those of Mr. D. Record 8, which is typical for this subject, shows no difference between the silent reading and breathing curves, both being perfectly regular and continuous lines. The writing curve shows a disturbing element, probably a faint inner speech. In Record 9* the silent reading curve clearly shows the presence of inner speech, but none appears in the writing. Out of a dozen records taken from this subject, this is the only one that shows inner speech in silent reading. The subject, however, read apparently in his usual way and was surprised at the result when I showed him the record. Record 10 shows the breathing, the silent reading, the writing, and the whispering curves from the four receptors. The only difference between the breathing and silent reading curves is the slower breathing in the latter. Some inner speech appears in the writing as is indicated by the sharp peaks which are similar to those in the whispering curve.

Record 11* shows the curves for counting mentally, in

whisper, and aloud from one to ten inclusive. The breathing for the mental counting is slightly more irregular than in the silent reading, but hardly enough to indicate inner speech. The great difference between this and the whispering and counting aloud curves makes this all the more probable. Record 12 shows the curves for addition and multiplication. Add 3 is the curve for a single column of figures, while Add 5 is the curve for adding a double column of figures at once. These columns were twenty-six digits high and contained no zeros. The subject had the card with the column before him and was told to add silently in his usual way. The use of a pencil was permitted, the subject writing down the result when the column was completed. It may be remarked that adding two long columns of figures at the same time is a very difficult process, much more so than the mental multiplication of three-place numbers. It would seem that in such a difficult mental process, inner speech would most certainly appear if it has any function at all, especially when the subject nears the upper end of the column. The curves, however, show no inner speech at any stage of the addition or mental multiplication processes, the curves being excellent specimens of pure breathing curves. The two lower graphs in Record 13 show two stages of the mental multiplication of a three-place number. The lower one is at the beginning while the upper one is near the end of the process. No inner speech appears. The third graph in Record 13 is the curve resulting when Mr. E. held the drum of the speech receptor between his lips while adding a single column of figures. I had noticed lip movements while Record 12 was taken and therefore took the lip graph. Mr. E. said that he always made these movements while adding but did not know whether they were of any use. They may result from his usual custom of adding aloud. Record 14 shows the curves for addition and mental multiplication from the four receptors. The absence of inner speech is conspicuous throughout.

Reporting his introspections, Mr. E. says that if he makes speech movements in silent reading he does not know it, but he experiences a peculiar tension about the throat and larynx,

and in the back of the tongue in writing. In his best reading he hears the sounds in his mind. Particular writers have their peculiar forms of auditory rhythm. He has a tendency to pronounce difficult words, and feels peculiar twists in his mouth when writing certain words, *e. g.*, incompetent. He has vague visual images of the printed forms in reproducing a passage in writing but he cannot read them. In the complete memorizing of a passage, these visual images either become very distinct or disappear entirely. He says they aid him in memorizing and recalling, especially the particular part of the page on which the statement was made. In mental multiplication he visualizes the process as if he were doing it with pencil and paper. And in addition he visualizes the products as he goes up the column.

Mr. E.'s introspections nowhere contradict his graphic records. The peculiar twists and the peculiar sensations in the back of the tongue that he experiences when writing is very probably a faint form of inner speech, as the graphic records show. His records and introspections also show that mental processes need not be conducted by inner speech as is the case with Mr. D., but can just as well be carried on in other forms of imagery, for example, auditory and visual.

In the case of Mr. A. inner speech does not appear either in silent reading or in writing as is shown by Record 15*; or in mental counting as is shown in Record 16*; very slightly in mental multiplication, as is shown by the three graphs above 68×59 mentally in Record 17*; inner speech appears slightly in the addition of a single column, as per the graph marked Add 11, and very marked in the addition of a double column, as per the graphs above Add 6. The most marked feature of the graphs for these arithmetical processes is the change in breathing. When the curve at the bottom, which is for normal breathing, is compared with those above, this change becomes very conspicuous. Breathing becomes much deeper and faster in the mental multiplication, shorter and slower while adding the single column, deeper and faster again for the adding of the double column. This seems to show that Mr. A. breathes faster and deeper while performing difficult mental problems.

According to his introspections, Mr. A. pronounces the words to himself in silent reading, in writing, in mental multiplication, and in addition, but he does not do so in mental counting. In mental multiplication he visualized the process while adding the partial products. He has occasional visual images of the objects read about, and these, he says, aid him in recalling. The graphic records show inner speech only for difficult arithmetical processes, but none in the silent reading or writing. His report of inner speech for the latter may easily be mistaken for auditory imagery.

The graphs of Mr. C. show a little inner speech for silent reading as per Record 18* and for addition as per Record 19* but none for mental multiplication. An interesting feature in the latter is that he held his breath. He multiplied 37×45 correctly in 14 seconds. He failed in 243×458 but held his breath during the entire attempt. This is additional proof that he did not use inner speech which I believe impossible while holding the breath. Mr. C. does not think he used any imagery in the mental multiplication except possibly touch and kinæsthetic and a little visual while adding partial products. He says he has muscular feels of the digits up to 20 as if going up a stairway. In ordinary life he adds aloud and describes the forms of figures in the air with his fingers. He thinks the speech receptor inhibited his usual processes. At any rate he added the columns correctly after it was removed.

Mr. B. does not show any inner speech in silent reading but it does appear in writing as per Records 20*, 21*, and 22. For Record 21 he read German where the reading curve is little more irregular than in Record 20. It scarcely evidences inner speech except a faint tendency.

It occurred to me that the little waves appearing in the writing curves might be due to the pulse. Instead of the abdominal breathing curve, I therefore took a graph for the pulse which appears in Record 22. There appears, however, no correlation between the little hills in the curve from the speech receptor and the pulse beats. In the section shown in Record 22 forty-eight pulse beats are shown in forty-three

seconds but sixty-seven little tongue movements are recorded, which shows clearly that the tongue movements are not due to pulse. Two other subjects tested for the same purpose showed similar results. Mr. B. showed no inner speech in the adding of a double column as per Record 23*; nor in mental counting, as per Record 24*; nor in the mental multiplication of 624 × 357, as per Record 25*. This was his first attempt at such a task which he found extremely difficult, but yet no inner speech appears in the graph.

According to his introspections taken after one performance, Mr. B. says he does not pronounce words in silent reading and in writing except in difficult cases. He gets the meaning direct from the visual form. In writing he believes the words come to his mind in their sound values. In adding he uses only auditory imagery. In mental multiplication he repeats the figures over to himself and visualizes the process as if done with pencil and paper. Records 20 to 25 are almost wholly in agreement with these introspections. For other performances, however, my notes state that he pronounces the words in reading, in writing, and in the arithmetical processes. Introspection thus yields contradictory reports. The graphic records, however, give important data for evaluating them.

Mrs. E., who was tested only for inner speech in reading and in writing, shows none in the former but it is quite marked in the latter. Reporting her introspections, she says that she pronounces words when writing but not when reading. This agrees with her graphic records.

According to Records 28* and 29, Mr. MC. does not use inner speech in silent reading. The little breaks in the writing curve indicate its presence there. This is more apparent in Record 29 than in 28. He uses it in a mild form in mental multiplication and in addition. In any case, the curve for these processes is more irregular than for the breathing alone. No inner speech appears in mental counting, which was probably done with the breath.

Reporting his introspections Mr. MC. says that in silent reading he hears the words in his mind, but he has a tendency

to pronounce in writing. In mental counting he used auditory imagery and breathing. In mental multiplication and in addition he said the figures over to himself but does not think he made speech movements except near the end of the process. In adding the partial products in multiplication he used visual imagery. With respect to inner speech these observations agree with the graphic records. They also indicate the adequacy of visual and auditory imagery as vehicles of thought.

According to Records 33 and 34*, Mr. M. does not use inner speech in silent reading but he does in writing. The meaning of the curve for inner speech in addition and in mental multiplication as per Records 35* and 36*, is doubtful, although the breathing is more irregular and occasionally a sharp peak appears. The change in breathing during mental multiplication and addition is particularly evident in Record 37*. During the 69 × 58 mentally this subject breathed on an average once every 2.8 seconds. After doing 243 × 458 mentally, and adding two single columns and one double column, he breathed only once in 3.2 seconds.

Reporting his introspections Mr. M. says that he does not use inner speech in reading, but has a tendency to do so in writing. In the latter process he has visual images of the printed forms and reads from these images, which, however, soon fade away. In mental multiplication he tried to visualize the process but failed while adding the partial products. This failure in imagery prevented him from getting the correct results. In addition he thinks he said the figures over to himself. The graphic records confirm his introspections on writing and in silent reading. They neither contradict nor confirm them on the other processes.

Mr. Mt. has a smooth breathing curve but the reading and writing curves are closely similar to the whispering curve, indicating very clearly the presence of inner speech in these processes, as per Record 38. Record 39 shows that he has a very marked inner speech in the mental multiplication of 37 × 45; very much less in multiplying 4356 × 7189 with pencil and paper; very little inner speech in the beginning of the addition of a column of figures, but very much when he

gets near the end. He also uses inner speech in mental counting as per Record 40*.

These records are in agreement with a theory that I had in mind while trying out these tests. After seeing that not all my subjects used inner speech in reading and in writing, which processes were highly automatized for all of them, they would have to do so when it came to a very difficult and new mental process, for example, the mental multiplication of a three-place by a three-place number, or the addition of a long double column. I supposed that when a subject came to the adding of the last partial product in the mental multiplication of three-place numbers, he could not keep the partials in mind and get the correct sum without continually repeating them over to himself. Such a task would be too difficult for visualization and therefore inner speech had to take on the function. With this in mind I arranged a series of tests having a graduated difficulty from simple to complex as follows: (1) Silent reading, (2) writing, (3) 37×45 mentally, (4) 258×463 mentally, (5) adding a single column, (6) adding a double column. I was, however, disappointed to find that most of my subjects gave not the least confirmation for my hypothesis. Inner speech was no more present for them in adding a double column than in silent reading. Record 39 is one of the few that confirm this hypothesis. It is interesting to notice that when Mr. Mt. multiplied 4356×7189 with pencil and paper, his inner speech almost disappeared. That is, when the process was conducted by perceptual symbols, the imagery dropped out, but when the perceptual symbols were removed, they were supplied by inner speech. If imagery has any use in the workings of thought, it seems reasonable that this should be its proper function.

Record 41* indicates that Dr. P. uses inner speech in silent reading and in writing. The interpretation of Record 42*, for which the four receptors were used, is more difficult. I experienced much difficulty in getting a good record from Dr. P. because the speech receptor irritated his tongue and made him swallow repeatedly, causing the needles from the

tambours to make sudden jumps and spoil the graph. But Record 41* is in agreement with his introspection.

According to Record 43*, Mrs. R. uses no inner speech in silent reading, but it appears quite distinct in her writing curve. For Record 44 she seems to have used it in both processes. In Record 45, it is not clear whether she used inner speech or not. Inner speech may be of a character to appear only on certain occasions. However, if this were true, it would be rather a strange fact, especially so if it appeared and did not appear under the same circumstances, as in case of these records. Mrs. R. uses no inner speech in mental counting, as is indicated by Record 46*. The portions of the *MC* graph not underscored are the graphs for counting from one to ten to the beat of a metronome once per second. The absence of inner speech in these graphs is evident when they are compared with the *WC* (counting in whisper) and *AC* (counting aloud) graphs, which have characteristic forms. These forms are more evident in Records 47* and 48* for which the drum rotated more rapidly. The accidental character of inner speech in case of this subject also appears in Record 49 and 50 for mental multiplication. According to the former she uses more inner speech in 98×67 mentally than 37×45 mentally and more in 258×63 mentally than in 98×67 mentally. That is, her inner speech increases with the difficulty of the problem. But according to Record 50* it is doubtful whether any inner speech appears either in 37×45 mentally or in 258×463 mentally. If inner speech was necessary in Record 49* it is difficult to see why it was not so in Record 50.

Reporting her introspections Mrs. R. says that she does not pronounce words in silent reading but hears them in her mind. These images are more vivid in writing. She thinks she sometimes pronounces the words in both processes. In mental multiplication she thinks the spoken names for the figures and visualizes the process as if done on paper. She had no difficulty in visualizing while multiplying mentally two-place numbers, but could not do it in three-place numbers, and therefore failed to get the correct result. She must

visualize the partial products in order to add them. So far as inner speech is concerned these observations do not contradict the graphic records. The more vivid auditory imagery in writing is possibly mistaken for inner speech.

It occurred to me that it might be interesting to discover whether the spoken names for the digits had a fixed graphic form. Records 51* and 52 are the results of this inquiry. In Record 51* the subject spoke one digit every 1.5 seconds. In Record 52 she counted according to a signal given by the experimenter. It shows the graph for each spoken digit in its clearest form. There is much variability in the graph for the same digit spoken at different times. For example, the 8's and 9's in Record 52 are so dissimilar that it is doubtful whether one of either pair could be identified by the other. Still taking the graphs for all the digits together there is a very general similarity, enough to indicate that the same cause produced them.

Record 53 shows the graphs from Mrs. R. for the same words which Mr. D. read for Record 4. If these two are compared, the only similarity seems to be that both graphs have numerous tall and steep peaks. It would be quite impossible to identify them as graphs for the same words. Although the graphs for the same words from the same subject are relatively similar, these two cases seem to show that they are relatively dissimilar for the same words from different subjects. If this would prove to be a general law, a graphic language, even for spoken words, would be an impossibility. They rather point to the possibility of graphic language for each individual, but in the opposite direction for the possibility of reading the silent thoughts of man by attaching a harness to his vocal organs.

According to Records 54, 55, 56* Dr. S. does not use inner speech in silent reading or in writing, or in mental counting, or generally in mental multiplication. Near the end of the last process, the graph takes on a new character as if the subject whispered softly. Whether he did so or whether his tongue trembled because of his mouth filling with saliva is difficult to say. It also might indicate inner speech during

the adding of the last partial products. The curves for each of these processes is not smooth but made up of numerous little vibrations. If they were absent in the breathing curve, they might indicate a slight inner speech, but as it is, it may simply be the result of a tetanic effect in the tongue muscles.

Reporting his introspections, Dr. S. says that he gets the meaning of words direct from their visual form in print. He might make incipient speech movements. He repeats words over to himself in writing, spells out long words; judges grammatical form with motor imagery by pronouncing words. He has no auditory imagery. He thinks he pronounced in the double column addition. He generally adds by counting aloud. The mental multiplication of 243×458, which he did correctly, although it was his first attempt, he performed on the ends of his fingers. When adding the partial products he projected the digits on the wall. His remarks on incipient speech movements and pronouncing are hardly proven by his graphic record. His introspections are interesting in emphasizing the absence of auditory imagery and the vivid presence of kinaesthetic imagery.

According to Record 57* Mrs. W. breathes more irregularly in reading and writing than in pure breathing. Whether this augurs inner speech is difficult to say. It easily might do so. She probably uses inner speech in mental counting. According to her introspections she does not use inner speech in either reading or writing or have auditory images. She has neither visual or any other sort of images.

If we make a collective summary of our graphic records for the thirteen subjects tested, Table I is the result. The existence or non-existence of inner speech is indicated by a + or − sign respectively. If the introspection agrees with the graphic records, it is indicated by a like sign to the right. If the record or report is doubtful it is indicated by a ?.

Summarizing the results roughly, we may say one fourth of the subjects use inner speech in silent reading, three fourths use it in writing, one fifth use it in mental counting, one third use it in mental multiplication and one half use it in addition. The first conclusion that appears from this is that inner speech is not a universal but an individual trait.

\+ = process in question is used.
− = " " " is not used.

Subject	Silent Reading		Writing		Mental Counting		Mental Multiplying		Addition	
	Graphic Record	Introspection	Graphic Record	Introspection	Graphic Record	Introspection	Graphic Record	Introspection	Graphic Record	Introspection
Mr. D.	+	+	+	+	+	+	+	+	+	+
Mr. E.	−	−	+	?	−	−	−	−	−	−
Mr. A.	−	+	−	+	−	−	+	+	+	+
Mr. B.	−	?	+	?	−	?	−	?	−	?
Mr. C.	+	−	−	−			−	−	+	−
Mrs. E.	−	−	+	+						
Mr. Mc.	−	−	+	−?	−	−	?	?	+	?
Mr. M.	−	−	+	+	−	−	?	−	?	+
Mr. Mt.	+	+	+	+	+	+	+	+	+	+
Dr. P.	+	++	+	+						
Mrs. R.	−	−	+	?	−	−	?	−	?	−
Dr. S.	−	−	−	?	−	−	?	−	−	+
Mrs. W.	−	−	−	−						
	4+	4+	9+	6+	2+	2+	3+	3+	5+	5+
	9−	8−	4−	2−	7−	6−	3−	5−	3−	3−
		1?		5?		1?	4?	2?	2?	2?

56 cases
34 agreements
5 disagreements
17 uncertain

A second conclusion that appears is that the graphic records upon inner speech are more often confirmed than not by introspection. Out of fifty-six cases appearing in the table, there are thirty-four agreements, 5 disagreements, and 17 uncertain. The chances are almost 2 to 1 that the introspections are correct. But if over one third of the introspections are wrong, it would be difficult to get scientific results from these alone. To separate the right and wrong cases, some objective tests are needed. The graphic records are of assistance here.

The discovery that inner speech is an individual trait does not tell us what its function is. If we could find a uniform set of circumstances in which it always appeared, we should be able to infer its function. But the facts seem to be that most people who use it at all, use it in every mental process. A few who do not use it in simple processes, use it in difficult processes. Many do not use it at all. The question is then:

Has inner speech any function in the thought processes for those who use it? I thought that this difficulty might be solved by eliminating inner speech in some processes for which it is ordinarily used and then check up the mental product. If the elimination of inner speech is found to deteriorate the mental product, we could hardly avoid the conclusion that it is of some use for the process tested. On the other hand, if it has no effect upon the mental product, then it would be of no use to the thought functions. With this hypothesis in mind I began an experiment for testing the function of inner speech.

The essence of my method was to have some subjects perform additions and read and write reviews of newspaper clippings while repeating aloud continuously and rapidly the sentence: "Jack and Jill ran down the hill." For purposes of comparison, each subject did a series of the same tests without distraction. I chose newspaper clippings because I thought they would come the nearest to be equally interesting and uniformly difficult for all my subjects. Each clipping was cut so as to have ten points, a point being considered as one complete idea, such as a sentence or clause intelligible by itself. Two hundred and ten of these clippings were cut, numbered on the back, and put into envelopes, each envelope containing eighteen clippings. Into each envelope were also put eighteen blank yellow sheets, and a score card with blanks for the following data: Number of reading, number of clipping, time of reading in minutes and seconds, and date. The envelopes were then handed to the subjects with the following directions written upon them:

1. Take *three* clippings from the envelope, beginning with the lowest number.

2. Place a watch before you and mark the time in minutes and seconds for beginning the reading.

3. At the set time turn over the first clipping and read it through once.

4. Mark the time of reading in minutes and seconds on the score card.

5. Note time again as in 2 and write on the yellow sheet all that you remember of the *sense* of the clipping.

6. Mark the time of writing on the score card.

7. Repeat 2, 3, 4, and 5 with the other two clippings.

8. Mark on the yellow sheet the number of each clipping. reproduced.

9. Fill out the remainder of the score card for each clipping.

10. Replace the three clippings in the envelope.

11. Repeat the exercise daily until all the clippings are read, and then return to the experimenter.

These specific directions were given because each of the subjects did the work by himself at his own time and place. They were qualified to do this since they were either graduate students or instructors in psychology.

Eight subjects were used. Six did three envelopes each, two did four each, and one did two envelopes. As will appear later, the order of distraction was varied among the different subjects, some beginning and some ending with distraction. After completion the abstracts were graded from 0 to 10, according to the number of points correctly reproduced.

To give an idea of the character of the clippings a few examples are reproduced herewith. The short slanting lines or marks cutting the lines of print, divide the clippings and abstracts into points as defined above.

To be Done without Distraction

Clipping No. 3

"Doolittle.—What I'm complaining of is that he has made a gentleman out of me./ Who ever asked him to do that?/ I was happy,/ I was a free man./ I have gotten money out of pretty nearly everyone,/ just as I got it out of you, Henry Higgins,/ when I needed it./ Now I'm hedged in, bound hand and foot,/ and everyone gets money out of me./ You ought to congratulate yourself, says my lawyer."/

Abstract No. 3

Some man formerly a crook was satisfied in his trade because of his happy state. A gentleman he now is. In turn he gives money rather than take unearned money.

Reading, 26 sec. Writing, 1 min. 45 sec. Grade, 0.

Clipping No. 162

"Washington, Feb. 25.—/Representative Palmer of Pennsylvania and Representative Sherley of Kentucky conferred with President Wilson today/ on ways to forward the plan for repealing the clause in the Panama Canal act/ that exempts American coastwise shipping from payment of tolls./

"The President has been reluctant about sending a message on canal tolls to Congress,/ or putting into writing the full reasons for asking for the repeal of the exemption clause./ It is said now, however, that instead of sending a formal message to Congress on the tolls question,/ the President may send a letter to some influential member asking the repeal of the exemption clause./ The letter is to deal as frankly with the tolls question as the exigencies of the international situation will permit./

"A steering committee has been formed consisting of Messrs. Palmer, Sherley, Adomson, and Covington to canvass the House./"

Abstract No. 162

Rep. Palmer of Penn. and Rep. Sherley of Ky. called yesterday on Pres. Wilson to confer on the matter of abolishing coastwise trade. The President has been reluctant about sending any bill to Congress dealing with this quest,/ but it is suggested that he will send a letter to some influential member explaining the situation frankly/ and ask the repeal of the bill./

Reading, 25 sec. Writing, 2 min. 25 sec. Grade, 4.

Clipping No. 157

"Mr. Mitchell referred twice to the Police Lieutenant's dinner./ He spoke of Col. Goetals as the prospective head of the department,/ and said the Colonel most certainly would accept the office if he could have the power to remove from the department those men whom he considered dangerous to the city's welfare./

" 'I wish I had not been ill on the night of the Police Lieutenant's dinner,' he continued,/ 'because I wanted to go there to tell them just what I am going to tell you. To

continue a man in the Police Department after he has been removed by the Commissioner is subversive of discipline/ and continues the "System," which has ruled the department as we know;/ the "System," that cohesive group which imposes itself on the department,/ compels honest men to stand by dishonest men,/ and so perverts sentiment that an Inspector under indictment can walk into a Police Lieutenant's dinner and be cheered for his refusal to answer questions put to him by the District Attorney./' "

Abstract No. 157

Mr. Mitchell referred twice to the Police Lieutenant's dinner./ He said Goetals would surely accept the position/ if he could have the power to remove those from the force he thought dangerous—/ I wish I had not been ill and could have been at the Police Lieutenant's dinner/ so that I could have told them just what I am going to tell you./

To continue a man in office after he has been dismissed by the Commission is subversive of all discipline/ and continues the system as we know./ It causes honest men to stand by dishonest men./ For a man to be cheered as he enters the dinner hall because he refuses to answer questions put to him by the district attorney is the condition of rule by a few known as the system./

Reading, 1 min. Writing, 4 min. 2 sec. Grade, 9.

WITH DISTRACTION

Clipping No. 34

"Our grandfathers did not give up $50 each for the privilege of spending New Year's Eve in crowded restaurants. Neither did they, at the stroke of twelve, put on caps of colored paper, ring cow bells, and throw confetti at strangers. Yet we, who ridicule their traditions and superstitions, can find, it seems, no more satisfactory way in which to speed the Old Year and welcome the New. Perhaps we might profitably follow their example."

Abstract No. 34

Our grandparents did not spend $50 each/ to spend New Year's Eve in a crowded restaurant./ Nor did they at the

stroke of 12/ put on paper caps,/ ring cow bells,/ and throw confetti at strangers./ Yet we deride their superstitions./ We might well follow their customs in our New Year's observance./

Reading, 20 sec. Writing, 2 min. 50 sec. Grade, 8.

In summing up the data one envelope of eighteen clippings was treated as a unit. From the eighteen reading times, or writing times, or grades the median was taken and the average deviation was taken from the median. Under the circumstances there was necessarily considerable variability in the data, a situation that prevents the average from giving the middle measure as well as the median. However, either method would give the same conclusions. Table II. shows the collected results of the clipping tests. They appear in graphic form in Plate VII. The *C* lines which measure the subject's comprehension are unaffected by distraction in the

Table II

For Clipping Tests

Time = seconds. Figures in parentheses = order in which the envelopes were read.

	Without Distraction						With Distraction					
	Reading		Writing		Grade		Reading		Writing		Grade	
	Time	A. D.	Time	A. D.	Value	A. D.	Time	A. D.	Time	A. D.	Value	A. D.
Mr. A.	(1)[2]29	3.8	108	22	4	1.2	(2) 28	4.4	125	29.6	5	1.0
	(4) 29	5.5	115	23.5	4	1.0	(3) 27	3.8	131		4	1.0
Mr. B.	(3) 35	10.4	150	42.2	6.5	1.2	(1) 90	81.1	233	67.2	4	1.0
							(2) 80	21.1	240	49.3	5	1.2
Mr. D.	(3) 38	10.5	130	20.3	4	1.0	(1) 22	5.6	115	12.5	4	1.0
							(2) 40	9.1	140	20.4	5	1.0
Mr. E.	(1) 35	5.5	165	30.1	6.3	1.37	(3) 55	15.3	206	47.7	6	1.33
	(2) 33	8.0	178	32	6	1.0	(4) 40	8.5	150	26	6	1.0
Mr. M.	(3) 32	4.5	72	21	4	1.6	(1) 40	6.66	80	25	3	1.0
							(2) 30	5.3	60	35.6	2	1.33
Dr. P.	(1) 27	3.4	87	18	3.9	1	(2) 30	3.6	108	25.4	4	1
	(3) 29	3.5	120	20	4	1						
Mrs. R.	(3) 30	5.5	150	26.6	7	1.33	(1) 30	5.1	130	21.2	5	.82
							(2) 25	6.7	120	28.8	5	1.44
Mrs. W.	(1) 39	9.0	82	32	2	0.7	(2) 29	4.5	52	13	1	.5

case of Mr. A., Dr. P., and Mr. E. According to the graphic records Mr. A. and Mr. E. did not and Dr. P. did show inner speech in silent reading. Removing the distraction increases

comprehension 1½ points for Mr. B., ½ point for Mrs. R., and 2 points for Mr. M., although none of them showed any inner speech in the graphic records. It lowered comprehension 1 point for Mr. D., who showed inner speech in its most marked form. Putting on the distraction lowered comprehension for Mrs. W., but she showed no inner speech in the graphic record. Practice effect may account for part of the improvement made by Mrs. R., Mr. M. and Mr. B., but this is hardly an adequate explanation, because after removing the distraction, practice is much more rapid for Mr. B.; for Mrs. R. the curve rises from a level, and for Mr. M. it changes from a downward to an upward direction. These changes coming directly after removing the distraction can hardly be due to any other cause. In general the 'Jack and Jill' distraction does not decrease the efficiency of thought for one subject who does not use inner speech and for three subjects who use it. Out of four subjects who do not use inner speech the efficiency of thought is improved for three by removing the distraction and lowered for one by putting on the distraction. If the graphic records are to be relied upon for the existence of inner speech, and if inner speech has any function in the efficiency of thought, the results ought to be just the opposite. The question is then whether the speech receptor failed to record the existence of inner speech, or whether the 'Jack and Jill' distraction failed to eliminate inner speech, or whether it affected primarily the attention. The speech receptor might not have succeeded in all cases, but it certainly did in some, and in those the distraction did not affect comprehension. If the distraction did not entirely eliminate inner speech, it could hardly have failed to interfere with it. But those who use it most show no interference in comprehension. The probability is then that the distraction interfered in some cases with the attention. Since repeating aloud one sentence while reading another in print are both voluntary processes more or less conflicting, one could hardly avoid shifting the attention between the two. Under the condition a subject could not give his whole mind to the reading alone. Removing the distraction would

enable him to do this, resulting in an improved comprehension. This seems to me the most probable explanation for the subjects who showed improved comprehension when the distraction was removed. But in any case the facts seem to show that in no case is inner speech indispensable to thought. In fact, I cannot see that it is of any use at all in the comprehension of meaning in reading.

Considering the differences between the last envelopes read with distraction and those read without distraction, we find that *removing* the distraction raises the median reading time 2 seconds for Mr. A., 5 seconds for Mrs. R., and 2 seconds for Mr. M. It lowers the median reading time 45 seconds for Mr. B., and 1 second for Dr. P. *Putting on* the distraction raises the median reading time 7 seconds for Mr. E., and lowers it 10 seconds for Mrs. W. We may say that the median reading time is unaffected, or at most only temporarily affected, by distraction for Mr. A., Dr. P., Mr. E., Mrs. R., Mr. M. and Mr. D. Of these four use inner speech and two do not. The only cases that call for explanation are those of Mr. B., Mr. E., and Mrs. W., neither of whom use inner speech. The drop of 45 seconds for Mr. B. is remarkable. If he used inner speech we might suppose that he repeated the words to be written during interruptions in the distraction, alternating between the two processes. His observation is that he found the distraction extremely difficult at first and possibly used inner speech in a few cases during interruptions, but he soon overcame this difficulty so that it did not bother him at all. These remarks together with his graphic records make it improbable that the drop in the reading time can be explained by the presence of inner speech. It seems very probable that the distraction badly disturbed his attention, making it necessary for him to reread many lines in order to get the thought. After the distraction was removed this rereading became unnecessary and therefore reduced his time. The same explanation would apply to Mr. E.'s case, but it would fail in Mrs. W.'s case for whom *putting on* distraction reduced the reading time ten seconds. For this case I have no explanation unless the

distraction caused her to put forth much greater effort or else read rapidly and carelessly. Her poor comprehension during distraction favors the latter hypothesis. But in all cases the variations in the reading time are much more easily explained by effects on the attention than by interference with inner speech. That the latter does not account for anything here is proven by the fact that the median times of the four subjects who use inner speech are unaffected by the 'Jack and Jill' distraction, whereas the reading times of three out of four who do not use it, are affected by the distraction.

It may also be noticed that with the exception of two cases, those of Mr. B. and Mr. E., the curves for the reading times and grades run closely parallel, that is, they rise and fall in the same general direction. This means that the faster the subjects read, the poorer they comprehended; and the slower they read, the better they comprehended. Such a correlation is contrary to what most other investigators have found upon this relationship.

The 'Jack and Jill' distraction has its greatest effect upon writing time. *Removing* the distraction *lowers* the median writing time 16 seconds for Mr. A., 90 seconds for Mr. B., and 10 seconds for Mr. D., *raises* it 13 seconds for Dr. P., 30 seconds for Mrs. R., and 12 seconds for Mr. M. *Putting on* the distraction *lowers* the median writing time 15 seconds for Mr. E. and 30 seconds for Mrs. W. That is to say, *removing* the distraction *lowers* the writing time for two who use inner speech in writing and for one who does not use it, and *raises* the writing time for three who use it. Putting on the distraction *lowers* the writing time for two who do not use inner speech in writing. In other words, the distraction *raises* the median writing time for two who use inner speech in writing and for one who does not, and *lowers* the median writing time for three who use it and for two who do not. This statement is derived by considering the removal of the distraction as having opposite effects if those subjects who first read and wrote with distraction and then without, would have read and written in the reverse order. Inner speech is present and not present in cases where distraction

has the same effect, or it is present in cases where distraction has opposite effects. If inner speech were important in the writing function for those who use it, distraction ought to raise their writing time very much, and have little effect upon those who do not use it. But according to the above facts, out of five subjects who use inner speech in writing, the 'Jack and Jill' distraction raises the median writing time for two and lowers it for three. This situation compels us to find some other explanation of the variation in the writing time. In the case of Mrs. R., Mr. M., Mr. D., and Mrs. W. the writing time and grade curves rise and fall together. This means that when the subjects remembered much, their writing time was high; and when they remembered little, their writing time was low. This is an intelligible relationship, for evidently it does not require so much time to write two lines as it does ten lines. The grade, however, does not explain the variation in the writing time for the other four subjects. In the case of Mr. E. and Dr. P., the *W* lines vary greatly while the *G* lines remain constant. For Mr. B. the *R* and *G* lines run in opposite directions. For Mr. A. they run both parallel and opposite. In the case of Mr. E. the first week of distraction raised the writing time 28 seconds, the second week lowered it 56 seconds. This suggests that the distraction temporarily disturbed his attention. His mind alternated between recalling the subject matter for writing and an effort to keep the distraction process going properly. During the second week the latter took care of itself, enabling him to give his whole mind to the recalling and writing. The same explanation would apply to the cases of Mr. A. and Mr. B. For Dr. P.'s case, where removing the distraction raised the writing time without raising the grade, I have no explanation. In general, however, I think the variation in the writing time must be sought in the variation of the attention and grade.

The general conclusion which the tests in connection with the newspaper clippings point to is that inner speech has no important function in comprehension in reading, and in writing, or in the rate of reading and writing.

The reading and writing tests were followed by a series of tests in addition. The series was made up of six sheets, each sheet containing sixteen single columns of twenty digits each, no columns having ones or zeros. The first and sixth sheets were done without distractions. The remainder were done with distraction, the same distraction as in the reading and writing tests. Only four subjects completed these tests, the results of which are shown in the curves of Plate VIII. The curves marked *S* represent the sum of errors for each sheet, those marked *C* represent the number of columns in each sheet added wrongly. The *S* and *C* curves therefore measure the same fact.

It will probably facilitate interpretation to make a table giving for each subject the average sum of errors made per sheet with distraction and without distraction; also the average number of columns per sheet added wrongly with distraction and without distraction. These are given in Table III.

TABLE III

	Without Distraction		With Diitraction	
	S'	*C'*	*S'*	*C'*
Mr. D.	19	3	11.25	7
Mr. M.	74.5	12.5	47.50	12.25
Dr. P.	1	1	10.50	2
Mrs. R.	17.25	5	41.75	5.75

S' = Average sum of errors per sheet.
C' = Average number of columns added wrongly per sheet.

We notice that two of the subjects add on the average more columns wrongly with distraction than without distraction. Distraction has no effect upon the number of columns added wrongly for the other two subjects. For two subjects the distraction increases the average sum of errors per sheet, and for the other two subjects it has the opposite effect. All of these subjects ordinarily use inner speech in addition. If inner speech is important for the addition process, the 'Jack and Jill' distraction ought to show its effects. It ought to increase the quantity of errors as well as the adding time for all the subjects. But this is not the

case with either the errors or the time. If the series of tests with distraction had been prolonged, we undoubtedly would have gotten the ordinary practice curve in spite of the distraction, which would probably show itself in slower improvement and greater variability in the early stages than a series without distraction. Such results are even shown in this series in case of Mrs. R., whose curves are typical practice curves. In such a case we should probably interpret the variability in the curves as a function of the attention.

The writer wishes to express his sincere gratitude to Professors J. McK. Cattell and R. S. Woodworth, in whose laboratory this experiment was done, and also to each of his subjects, namely: Drs. Poffenberger, Strong, and Evans; Messrs. Anderson, Brimhall, De Bra, McCall, Martin, and May; and Mrs. Williamson and Mrs. Reed, all of whom assisted him at a great sacrifice of their time.

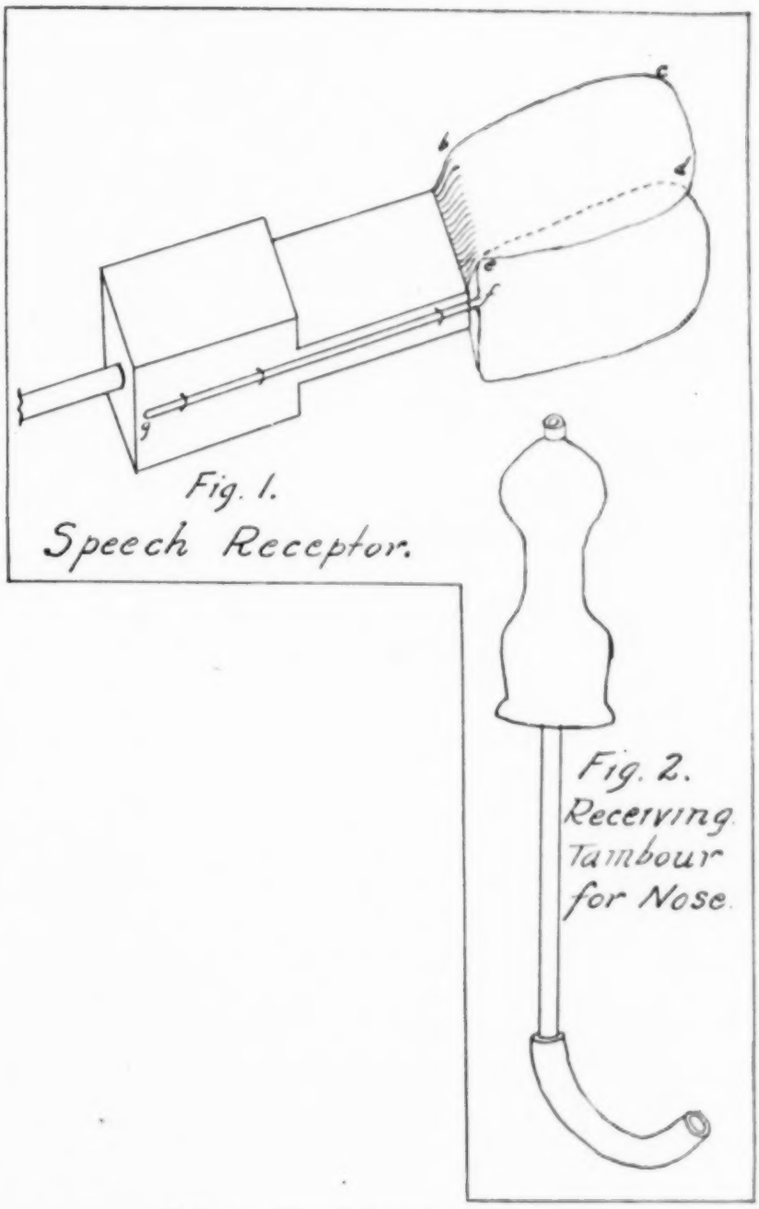
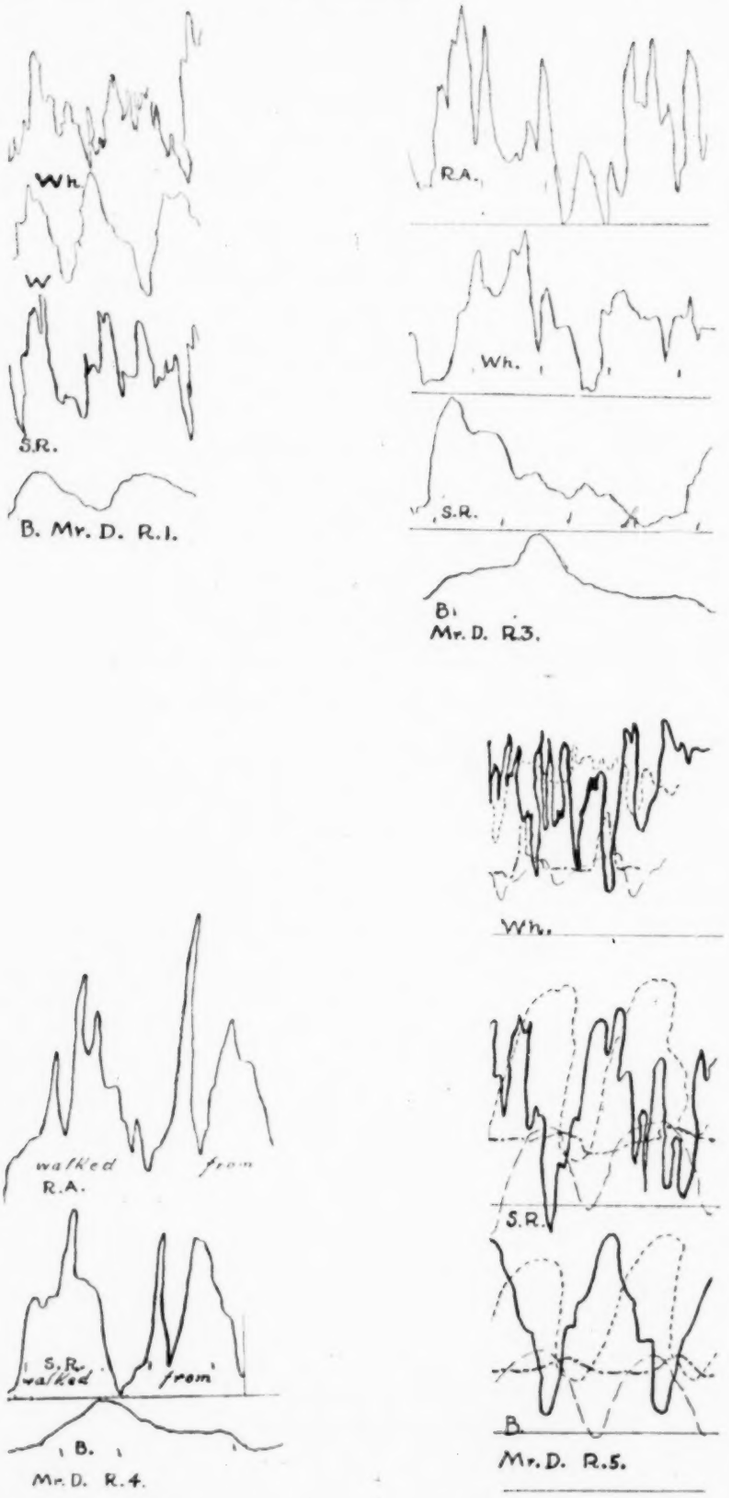
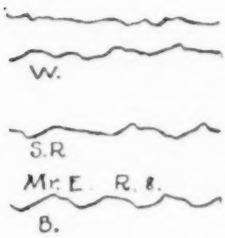


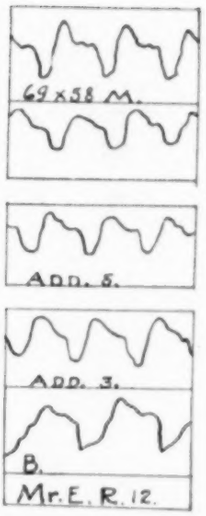
Fig. 1. Speech receptor.
Fig. 2. Receiving tambour for nose.

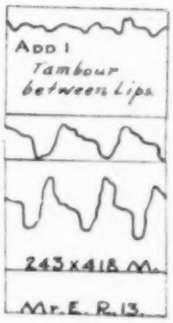


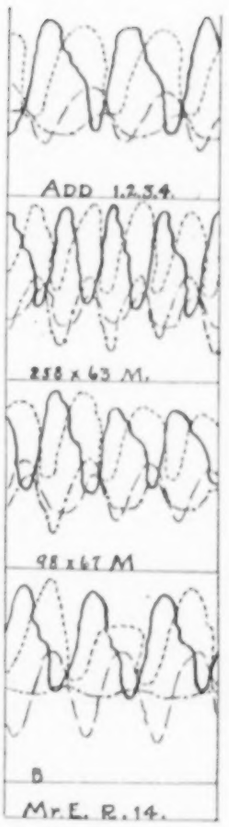
R. 1, *R.* 3, and *R.* 4, are tongue curves. In *R.* 5 the heavy continuous line represents the curve from the speech receptor. The line of short dashes represents the curve from the tambour in the nose. The line of long dashes represents the curve from the pneumograph around the chest. The line of dots and dashes represents the curve from pneumograph around the abdomen. The same is true of similar cuts.

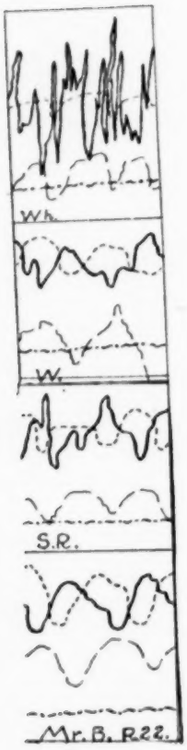

W.
S.R
Mr.E. R. 8.
B.

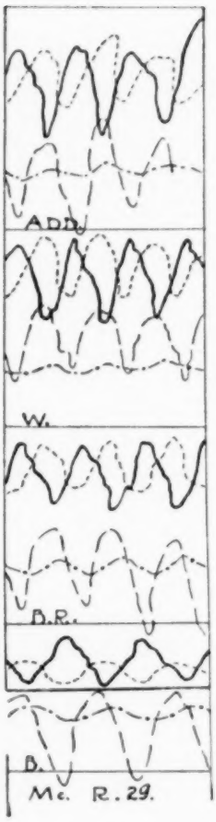
Wh.
W.
S.R.
B.
Mr.E. R.10.

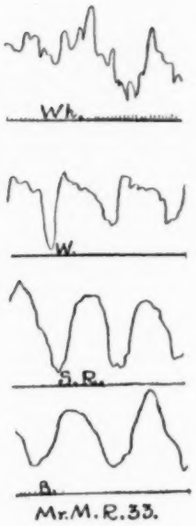

69x58 M.
ADD. 5.
ADD. 3.
B.
Mr.E. R.12.

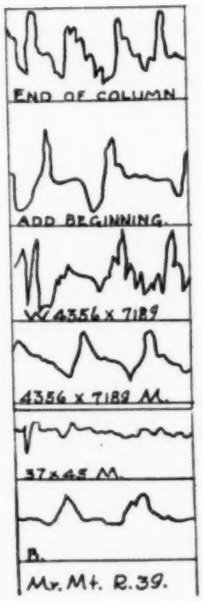

ADD 1
Tambour
between Lips
243x418 M.
Mr.E. R.13.

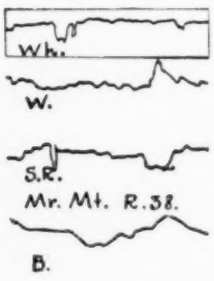

ADD 1.2.3.4.
258 x 63 M.
98 x 67 M
B
Mr.E. R.14.

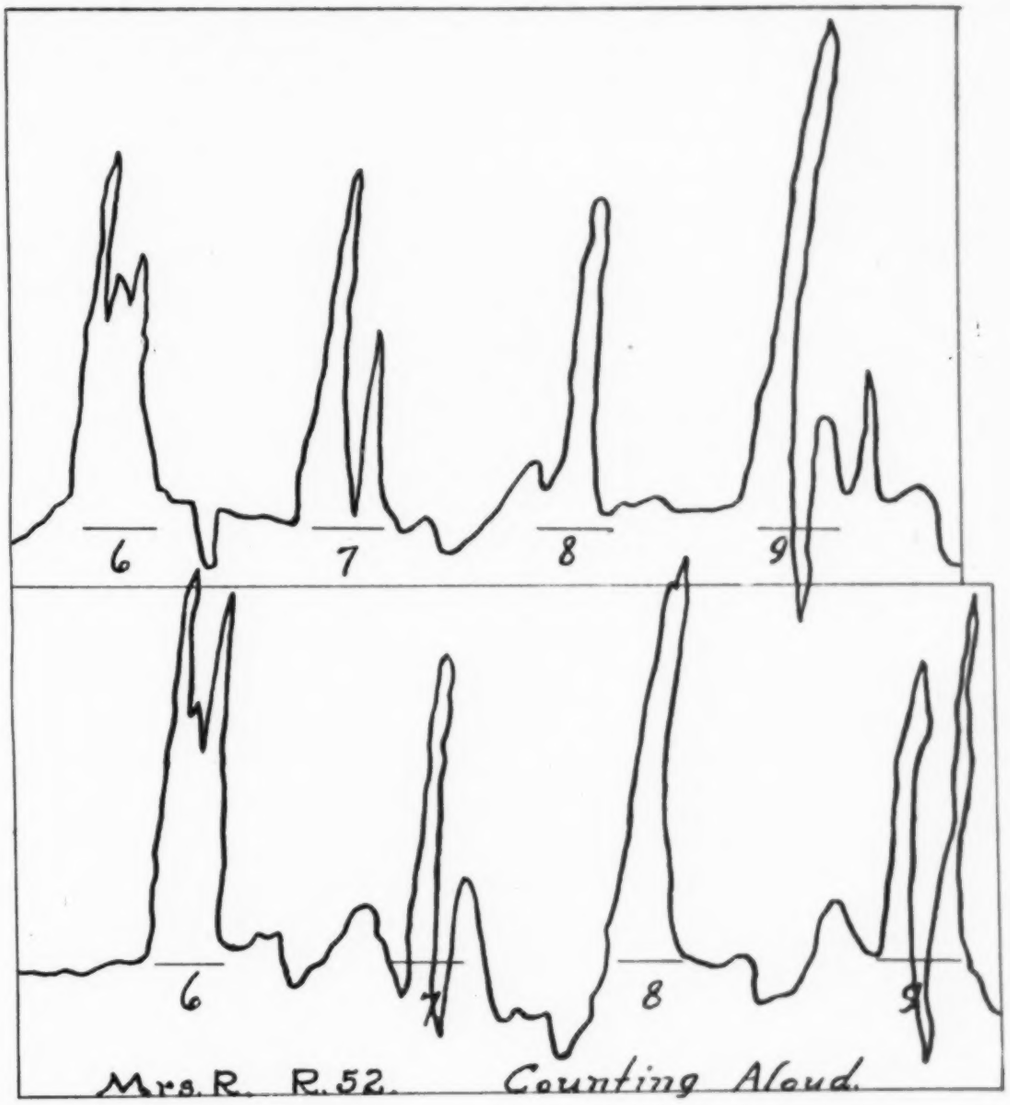

Wh.
W.
S.R.
Mr. B. R22.


ADD.
W.
D.R.
B.
Mc. R. 29.


Wh.
W.
S.R.
B.
Mr. M. R. 33.


END OF COLUMN
ADD BEGINNING.
W. 4356 x 7189
4356 x 7189 M.
37 x 45 M.
B.
Mr. Mt. R. 39.


Wh.
W.
S.R.
Mr. Mt. R. 38.
B.


6
7
8
9
6
7
8
9
Mrs. R. R. 52. Counting Aloud.

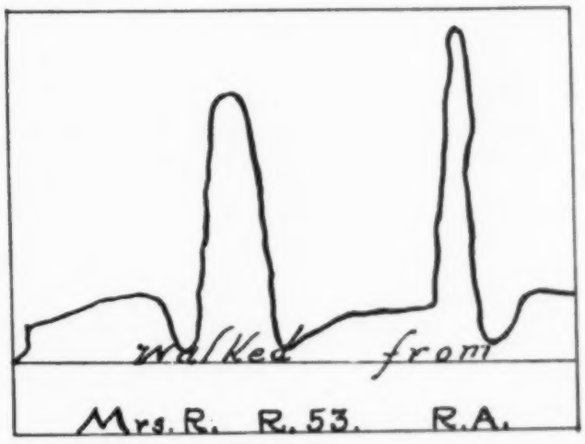
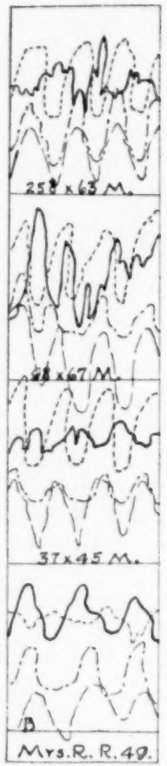
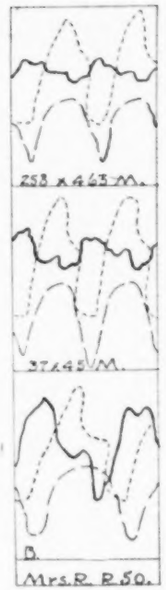

Walked from
Mrs. R. R. 53. R. A.

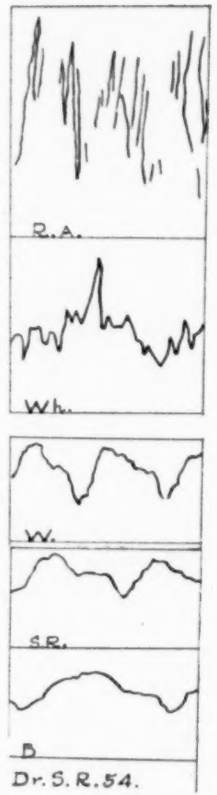
PLATE 6.

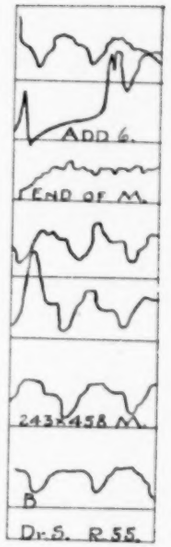
Wh.
W.
S.R.
B.
Mrs.R. R.44.

R.A.
W.
S.R.
B
Mrs.R. R.45.


258 x 463 M.
28 x 67 M.
37 x 45 M.
B
Mrs.R. R.49.


258 x 463 M.
37 x 45 M.
B
Mrs.R. R.50.


R.A.
Wh.
W.
S.R.
B
Dr.S. R.54.


ADD 6.
END OF M.
243 x 458 M.
B
Dr.S. R.55.

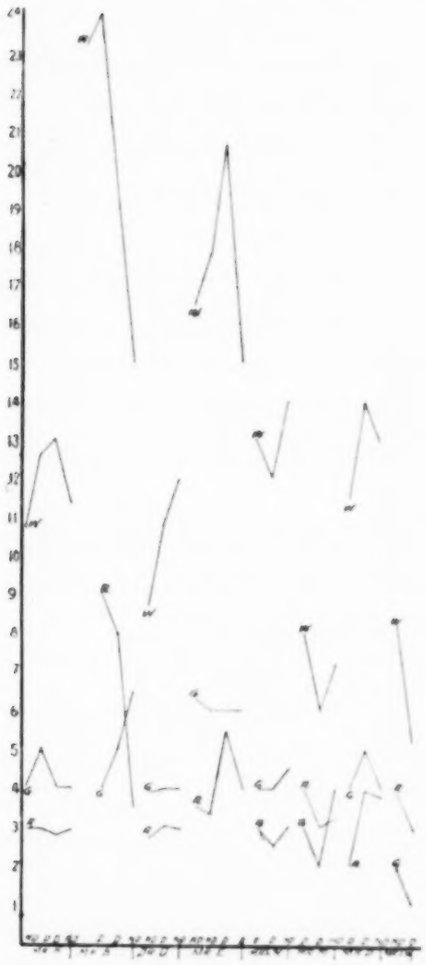


Fig. 4. Clipping tests: *W* = writing T per 18 clippings. *R* = reading T per 18 clippings. *G* = grade. *D* = with distraction. *ND* = no distraction.

1 cm. along vertical = 24 secs. for T lines
= 2.4 " for R and G lines

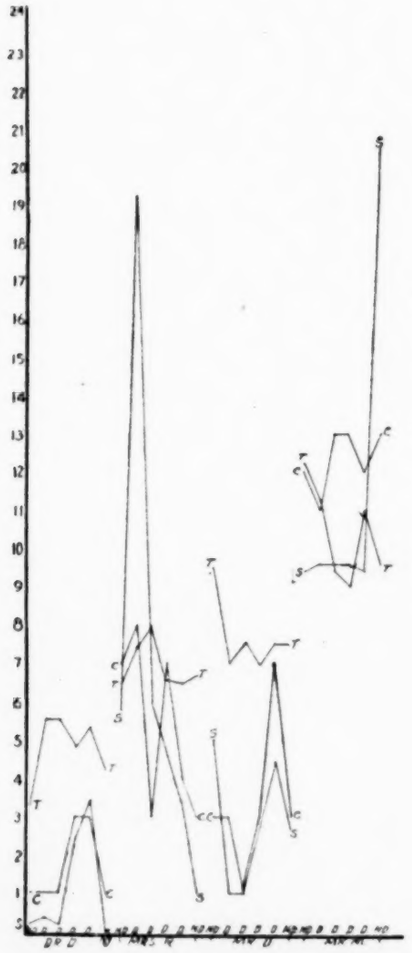


Fig. 5. Addition tests. S = sum of errors = 5. T = time per 16 columns. C = number of columns wrong. D = with distraction. ND = no distraction.

1 cm. along vertical = 2.4 mins. for T lines
= 12 " " S "
= 24 " " C "

THE MNEMONIC SPAN FOR VISUAL AND AUDITORY DIGITS[1]

BY ARTHUR I. GATES

A small amount of experience in testing immediate memory for digits led the writer to the belief that the quantity of material presented was an influential factor in determining an individual's capacity. Accordingly the following experiment, which aims to find the exact span of a number of individuals and to discover the effects of increasing the presented series beyond the span, was planned and carried out. The investigation has yielded some information with regard to the adequacy of single long series of items as a test for memory,[2] as well as some interesting results with regard to individual differences.

About 165 college students completed the tests, working in groups of from eight to fourteen persons, each group at a different hour, the earliest beginning at 8:10 a.m. and the latest at 5:10 p. m. The program covered two full days.

For auditory tests, which were always given first, the following series of digits were used: 9627, 41852, 736294, 8513627, 38471629, 529468371, 2574638197, 83519472631, 628194357283. By means of a silent pendulum, invisible to the subjects, the digits were spoken to them at the rate of one to each three fourths of a second, clearly and sharply, and without rhythm.

Similar series were prepared for visual tests. Black figures two and three fourths inches in height were mounted on white cards (two and a half by three and a half inches) and these cards were pasted on a narrow strip of gray cloth. The series were: 6283, 57294, 241738, 2170463, 27985543, 215903847, 5978024318, 57402623871, 183570467392. The strip could be folded in the hands, held before the subjects

[1] From the Psychological Laboratory of the University of California No. XXIV.

[2] For a summary of methods of testing memory see A. Pohlmann, *Experimentelle Beiträge zur Lehre vom Gedächtniss*, Berlin, 1906.

and quickly displayed by drawing it taut with a snap. The total time of exposure in this case was the same as that for the auditory series, *i. e.*, three fourths of a second was allowed for each digit.

In both cases the subjects were called to attention just before each test was made. At the word "ready" the test was started. The instructions, to write down the numbers immediately after the exposure but to write nothing until the series had been taken from sight, were carefully followed. Ample time was allowed between tests for the subjects to write down the digits remembered and to prepare for the next test.

The results were scored by counting the number of digits which were correct in form and position. A digit was considered as being correctly placed if its position was correct when measured either from the left or the right of the series.

By the 'span' of memory is meant, in this paper, the longest series of digits which, after exposure, an individual can accurately reproduce entire. If a series of digits is exposed, of which the individual can reproduce only a part, the number reproduced is always spoken of as the 'number reproduced' or 'recalled,' etc. The terms 'exposure series' or 'presentation series' refer simply to the group of digits read or shown.

Difficulties were sometimes encountered in deciding what series should be taken as the span. For example, an individual may reproduce a series of seven digits, fail at eight, succeed at nine and fail thereafter. Another may reproduce seven, fail at eight and at nine, and succeed at ten. When there is but one failure immediately followed by a success, the latter is taken as the span. Thus in the first example the span would be nine. In case more than one failure followed a success, the number before the failures would be considered the span; thus in the second example seven digits would stand as the span.

The Average Span of Visual and Auditory Digits

With the auditory method of presentation the average span was 7.666 digits. The same individuals reproduced on

the average, 8.172 digits when these digits were presented visually. The mode is 8 digits with either method; a relatively greater number falling upon it in the case of the visual method. The tendency in the direction of a larger span in the case of visual presentation is shown by the table of distribution (Table I.). A greater number (14 more) surpass the modal span and a smaller number (19 less) fall below the mode.[1]

In the visual method, since mode and average nearly coincide and since the average span is above eight digits, the norm for adults of good training could with reasonable security be placed at eight digits. We can, more exactly, say that the normal individual should reproduce a series of at least eight digits when presented visually at the rate of one for each three fourths of a second.

The selection of the normal span in the case of auditory digits is less easy. The modal span is eight, but the average falls below that by one third of a digit. The number of individuals unable to span eight digits is greater by 7.2 per cent. than the number which exceeds the modal span. Although to set the normal span at eight digits would not be strictly correct, for practical purposes there is no choice other than eight digits for the norm.

Table I. shows that when the number of digits exposed surpasses the span, the distribution of individuals become mor extended. A greater number recall but very few (0, 1, 2, 3, or 4) digits and nearly as many recall very many (10, 11, or 12) digits. The curve of distribution in the cases where the series exposed is longer than the span, compared with the curve in the case where the series exposed equals the span, appears skewed toward the lower end.

[1] The opportunity afforded the subjects to read the very short series of digits more than once in the visual series may explain, partly at least, the fact that a smaller number of individuals have short spans. Miss Ada Felt, who coöperated in the tests, gave her attention to noting the methods employed. She found that many subjects, unless warned, wrote down the short series before the exposure was complete. Since this practice was not permitted, some glanced aside and repeated the numbers to themselves and others reread the series one or more times. As the series became longer, all the subjects devoted their whole time to reading the series, generally completing them but once although the time per digit was the same as in the short series.

The Influence of Presenting a Series of Digits Which Exceeds the Span

If eight digits is the largest number that a particular individual can retain and reproduce correctly, what will be the result when nine, ten, or more digits are presented?

Table I. shows that an increase in the number of digits exposed has an unfavorable influence on immediate memory. In no group is the average number of digits remembered equal to the average span. In every case except one the difference amounts to more than two digits. In the single case which forms the exception, the difference is nearly two, and in other cases it is nearly three digits. The average reduction amounts to 25.9 per cent. with the visual method, and to 36.6 per cent. with the auditory method.

Table I., Section (5), shows that the facts found in the

Table I

Showing the Number of Individuals Reproducing Various Numbers of Digits When the Exposure Series Was the Exact Length of the Span, One Digit Longer than the Span, Etc.

Visual Series

No. Digits	Span, No. Inds.	Span + 1, No. Inds.	Span + 2, No. Inds.	Span + 3, No. Inds.	Span + 4, No. Inds.
12	3	0	0	0	1
11	4	0	1	1	1
10	13	1	6	2	2
9	35	8	7	8	6
8	63	14	20	15	15
7	29	37	27	32	17
6	15	44	42	34	22
5	2	32	20	21	11
4	0	13	14	14	11
3	0	5	5	9	7
2	0	5	10	4	4
1	0	1	2	1	5
0	0	0	2	2	5
Total No. inds.[1]	163	160	156	143	107

	At Span	At Span + 1	At Span + 2	At Span + 3	At Span + 4	
1. Av. span of inds.	8.172	8.10	8.03	7.84	7.54	
2. Av. No. digits recalled		5.98	5.94	5.90	5.51	
3. Diff. between span and av. No. recalled		2.12	2.09	1.94	2.03	
4. Diff. in per cent.		26.00	26.00	24.80	27.00	Av. 25.9
5. Mode	8	6	6	6	6	

Auditory Series

No. Digits	Span. No. Inds.	Span + 1. No. Inds.	Span + 2. No. Inds.	Span + 3. No. Inds.	Span + 4. No. Inds.
12	2	0	0	2	0
11	1	0	0	2	2
10	9	1	1	1	1
9	29	2	2	5	0
8	56	17	14	9	5
7	30	20	25	10	9
6	23	33	30	20	17
5	12	38	26	23	18
4	0	25	21	24	20
3	0	14	17	20	17
2	0	5	14	16	14
1	0	4	3	10	7
0	0	1	6	8	10
Total No. inds.[1]	162	160	159	150	121

	At Span	At Span + 1	At Span + 2	At Span + 3	At Span + 4	
1. Av. span of inds.	7.666	7.61	7.59	7.44	7.07	
2. Av. No. digits recalled		5.30	4.96	4.50	4.09	
3. Diff. between span and av. No. digits recalled		2.31	2.63	2.94	2.98	
4. Diff. in per cent.		30.40	33.30	39.50	42.10	Av. 36.6
5. Mode	8	5	5	4	4	

[1] When the series is increased beyond the span, certain individuals are eliminated from the group. Those whose span was 12 digits are eliminated from the group "Span + 1" because a series of 12 digits was the longest given. When we reach "Span + 2," those whose span was 11 and 12 digits are eliminated, and so on. The average span of the group becomes smaller, consequently, as the number of individuals decreases.

general averages are characteristic of the group showing the central tendency. In the case of visual memory, to increase the number of digits exposed beyond the span means to decrease the modal figure by 25.0 per cent. which is identical with the reduction in the average figures. The decrease is greater for auditory digits, a distinction which was also found in the average results.

Table II. gives the directions of change, without regard to the amount, as 'up,' 'down,' or 'the same.' The tabulations were obtained by noting the number of individuals who remembered more ('up'), less ('down'), or 'the same' number of digits when the length of the exposure series is increased.

The figures show that the distractions offered by too long

a series either are not effective for all individuals or are not effective for some individuals at all times. On the average, however, 77.1 per cent. of the individuals, when the visual method is used, and 84.5 per cent. with the auditory method, fall below their span when the series exposed is longer than the span. That is to say, only one individual out of four, when the visual method of presentation is used, or one out of six with the auditory method, is able to equal or surpass his span. But one out of ten, with the visual method, or one out of eighteen with the auditory method, is able to surpass his span.

The Influence of the Amount by Which the Number Exposed Exceeds the Span

Table I., Sections (1), (2), (3), (4), gives the average decrease in the number of digits recalled as the series becomes

Table II

Showing the Absolute and Relative Number of Individuals Who Remember More, Less, or the Same Number of Digits as the Exposure Series Is Increased

Visual Series

		Span + 1		Span + 2		Span + 3		Span + 4		Average
		No.	Per Cent.	No.	Per Cent.	No.	Per Cent.	No.	Per Cent.	Per Cent.
	"Up"....	0	0.0	19	12.2	19	13.3	15	14.0	9.9
	"Same".	7	4.5	23	14.7	23	16.9	18	16.8	13.0
	"Down".	153	95.5	114	73.1	101	70.8	74	69.2	77.1
1. From Span to.....	Total....	160	100.0	156	100.0	143	100.0	107	100.0	100.0
	"Up"....	...	.....	67	43.0	59	41.2	50	46.7	43.6
	"Same".	...	.....	27	17.0	28	19.6	16	15.0	17.3
	"Down".	...	.....	62	40.0	56	39.2	41	38.3	39.1
2. From Span + 1 to....	Total....	...	.....	156	100.0	143	100.0	107	100.0	100.0
	"Up"....	...	.....	...	.....	63	44.0	54	50.3	47.15
	"Same".	...	.....	...	.....	17	12.0	11	10.5	11.25
	"Down".	...	.....	...	.....	63	41.0	42	39.2	41.6
3. From Span + 2 to....	Total....	...	.....	...	.....	143	100.0	107	100.0	100.0
	"Up"....	...	.....	...	.....	...	.....	47	44.0	
	"Same".	...	.....	...	.....	...	.....	19	17.7	
	"Down".	...	.....	...	.....	...	.....	41	38.3	
4. From Span + 3 to....	Total....	...	.....	...	.....	...	.....	107	100.0	

Auditory Series

		Span + 1		Span + 2		Span + 3		Span + 4		Average
		No.	Per Cent.	No.	Per Cent.	No.	Per Cent.	No.	Per Cent.	Per Cent.
	"Up"....	0	0.0	13	8.1	15	10.0	6	5.0	5.8
	"Same" .	8	5.0	27	16.9	11	7.0	12	10.0	9.7
	"Down".	154	95.0	120	75.0	124	83.0	103	85.0	84.5
1. From Span to.....	Total....	162	100.0	160	100.0	150	100.0	121	100.0	100.0
	"Up"....	...	.....	59	37.0	52	34.6	31	25.9	32.5
	"Same" .	...	.....	33	20.6	17	11.3	11	9.1	13.7
	"Down".	...	.....	68	42.5	81	54.0	79	65.0	53.8
2. From Span + 1 to....	Total....	...	.....	160	100.0	150	99.9	121	100.0	100.0
	"Up"....	...	.....	...	.....	63	42.0	48	39.6	40.8
	"Same" .	...	.....	...	.....	20	13.0	17	14.0	13.5
	"Down".	...	.....	...	.....	67	45.0	56	46.4	45.7
3. From Span + 2 to....	Total....	...	.....	...	.....	150	100.0	121	100.0	100.0
	"Up"....	...	.....	...	.....	...	.....	50	41.3	
	"Same" .	...	.....	...	.....	...	.....	17	14.2	
	"Down".	...	.....	...	.....	...	.....	54	44.5	
4. From Span + 3 to....	Total....	...	.....	...	.....	...	.....	121	100.0	

longer. When the visual method of presentation is used, the amount by which the exposure series exceeds the span seems to have little effect, for only one series (Span + 4) shows a smaller number of digits recalled than at Span + 1. When the auditory method is employed the case is different. As the exposure series becomes longer, the difference between the span and the number recalled becomes greater.

The modal figures for the different visual series are identical, but in the auditory series, the modes for Span + 3 and Span + 4 are the smallest, indicating an unfavorable effect of very long exposure series.

Table II., Section (1), shows, that using the visual method of display, the number of individuals who are unable to equal their span becomes less as the exposure series becomes longer. But in the auditory series, the opposite is true. A striking feature in both cases is the relatively large number of subjects who go 'down' when the exposure series just exceeds the span (Span + 1) although the average number of digits recalled is as great in the auditory series and nearly as great in the visual series.

The effects of increasing the length of the exposure series can be seen from different points of view in Table II. by referring to Sections (2), (3), and (4) in which Span + 1, Span + 2, and Span + 3 are used as a basis of comparison. With the visual method, it is noticeable throughout that as the series becomes longer the number of individuals going 'down' becomes less, while in the auditory series the opposite is the case. The regularity with which these changes take place can be seen by glancing down the vertical columns or by scanning the table diagonally from left to right. In the auditory series the relations are quite regular, showing that the difficulty of recalling digits increases with fair uniformity as the exposure series are lengthened by uniform additions.

The results seem to justify the conclusion that as the series of digits given orally exceed the span by uniformly increasing amounts, conditions become more and more unfavorable for immediate memory. This rule, however, does not hold for the visual method of presentation. Perhaps a partial explanation of this difference lies in the fact that many individuals purposely neglected certain digits in the very long visual series and held to a number of digits at the beginning or end of the series to make up a number equal to that which they believed to be their limit. This could be more easily accomplished with the visual method since the series were exposed entire and because such a distracting influence as the reading of other digits was not present. Moreover since the visual series were given after the auditory series, many individuals, profiting by practise, were able to adjust themselves to the situation more effectively.

Types of Individuals

As soon as the span is passed most individuals are unable again to recall as many digits as at that point. Yet in a small number of cases, individuals succeed in equalling or surpassing their span.

To determine whether such results were caused by comparatively distinct types of individuals or whether they repre-

TABLE III

SHOWING THE PERCENTAGE OF INDIVIDUALS WHO EQUAL OR SURPASS THE SPAN AND THE NUMBER OF TIMES THIS IS DONE IN THE SERIES
SPAN + 1, + 2, + 3 AND + 4

Number of times (Visual Series)	Once	Twice	Thrice	Four Times	Once	Twice	Thrice	Four Times	Equal Once and Surpass Once	Equal Once and Surpass Twice	Equal Twice and Surpass Once	Equal Twice and Surpass Twice
Per cent. of inds.....	17.80	12.30	0.00	0.00	8.40	1.87	0.93	0.00	8.40	2.80	2.80	0.93
			0.00				0.93			6.53		
						7.46						
(Auditory Series)												
Per cent. of inds.....	18.30	8.26	0.82	1.65	9.15	2.50	0.00	0.00	5.00	2.50	3.30	0.00
			2.47				0.00			5.80		
						8.27						

sent merely exceptional performances by normal individuals, Table III. was compiled, showing the number of times that the subjects equalled or surpassed their span.[1]

Table III. shows that a comparatively large number of individuals either equal or exceed their span but once. Such performances can scarcely be considered those of a special type of individuals distinct from those who do not equal their span. There is, however, a smaller group who succeed in equalling or surpassing their span more frequently. If an individual accomplishes this feat three or four times out of four possible times, the performances seem to lie within the normal power of the individual. Consequently, this group, numbering about eight out of one hundred individuals, will be considered as forming a type comparatively distinct from the larger group whose members never or very seldom equal their span.[2]

[1] This tabulation is based on the results of those individuals whose span was eight digits or less. The series Span + 1, + 2, + 3, + 4, only were used.

[2] Of course, there are intermediate stages between the two groups. Thorndike's objection to calling the extremes of such a distribution "types" is worth considering. See his *Educational Psychology*, Vol. III., Chap. 16. The term has been used here for want of a better one.

Correlation of the Tests

For measuring the correlation of the two forms of tests, the following familiar formula was used:[3]

$$r = 1 - \frac{6\Sigma D^2}{n(n^2-1)}.$$

When the span is taken as the basis for measurement, a correlation of + 0.625 is found. This correlation is high enough to be significant.

Correlations were also computed for memorial efficiency in the two forms of test when the series of digits exposed were longer than the span. A sum was made of the total number of digits correctly recalled from the three longest exposure series (the series of 10, 11, and 12 digits) for those individuals whose spans were nine or less digits. The correlation was computed on the basis of these figures and a coefficient of + 0.225 was found. This correlation is small compared to that found when the computations are based on the span. Differences in method of presentation of the material, and perhaps differences in the form that practise-effects may take, account, in part, for the low correlation.

Summary

1. The average span for college students is approximately 8.2 digits when the visual method of presentation is employed, and 7.7 digits with the auditory method.

2. An increase in the number of digits exposed beyond the number constituting the span results in a more extended distribution of individuals.

3. An increase in the number of digits exposed beyond the span decreases the number of digits that can be recalled.

(*a*) Under these conditions, the number of digits recalled is 25.9 per cent. less than the span when the visual method is used, and 36.6 per cent. less when the auditory method is employed.

(*b*) Consequently, in group-tests, if a single series of 10, 11, or 12 digits is used, we should add to the number recalled one fourth when the visual method is employed or one third

[3] See Thorndike, E. L., 'Mental and Social Measurements,' 1913, p. 162.

with the auditory method, to obtain the average span of the group.

4. Two types of individuals appear when the exposure series is longer than the span.

(*a*) Most individuals are never or very seldom able to equal or surpass their span.

(*b*) A few individuals (about 8 per cent.) always or nearly always equal or surpass their span.

5. A correlation of + 0.625 is found for the individuals in the two tests when the span is taken as a basis of comparison; + 0.225 when the exposure series surpasses the span.

THE CORRELATIONS BETWEEN DIFFERENT MEMORIES[1]

BY FAYE BENNETT

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The purpose of the present investigation is to determine the correlations between immediate and mediate retention for auditory and visual presentation with various sorts of material.

Experiments and Results

The belief that retentiveness is a function dependent in large measure upon the plasticity of the nervous system, the fact that rather high correlations of abilities are shown by a study of results obtained in school subjects, and the common observation that memory efficiency among normal individuals is not highly specialized, led to the belief that we should find in the following study evidence indicating high correlations in memorization.

The materials selected for the tests include nonsense syllables of three letters; numbers of two digits; concrete nouns of four letters; descriptions of approximately one hundred and thirty-five words; narratives of approximately one hundred and fifty-five words; expositions of one hundred words for mediate retention; and expositions of two hundred words for immediate retention; memory for faces was tested by means of photos cut from college annuals. Except in the last mentioned tests visual and auditory presentations were given, reversing the alternatives in successive tests.

The observers selected to be tested include two professors, four graduate students and three seniors of the University of Wisconsin. Two of the graduate students and two of the seniors had had no previous experience in laboratory work.

In testing mediate and immediate retention for discon-

[1] Grateful acknowledgment is due to Prof. V. A. C. Henmon, of the University of Wisconsin, for guidance and many hours of coöperation in this piece of work.

nected or non-significant materials, each series was placed on the Müller Kymograph drum 50 cm. in circumference, and revolving at the rate of fifteen seconds; the aperture of the screen permitted the observer, in the visual presentation, to see each unit of the respective series for ¾ seconds. In the mediate material the number of repetitions was registered automatically by the kymograph.

The tests were administered in hour periods, an hour usually sufficing for the mediate learning of one series of each type of disconnected material visually and a corresponding one auditorily; in the immediate material four successive series of each type were presented visually, and four auditorily. The variability in rapidity of learning connected material caused a little more irregularity in the amount of work accomplished per hour. The total time required for each observer varied from fourteen to eighteen hours. The order of presenting the materials as well as the order of the methods of presentation varied from day to day so that any effects of fatigue might thus be counterbalanced.

Results

Disconnected Material for Immediate Retention

The successive or memory-span method was used to determine retention with three series of 4, 5, 6, and 7 syllables; 4, 5, 6 and 7 numbers; and 6, 7, 8, and 9 nouns, for each method of presentation. The scores were expressed in per cent. as calculated from the relation of the number of units retained to the number of units presented. The per cent. rather than a single figure was used as the measure of retention because of the variations of each subject in his performances; not only did these vary from day to day, but the same set of series often showed peculiar fluctuations, so that it seemed quite impossible to indicate the memory-span accurately by a single figure.

In deducting for errors, omissions and substitutions each counted one unit; transpositions counted one half unit; errors of one letter in the nouns and syllables, one half unit;

errors of one digit in the numbers, one half unit; errors of two letters in nouns or syllables were rates as substitutions.

Connected Material for Immediate Retention

These selections included one description, one narration, and one exposition for each method of presentation. For the visual tests the observer was directed to read the selection silently, and rather slowly, that the results might be more comparable to the corresponding selections presented auditorily. Immediately after finishing the reading the subject wrote the substance of the selection.

In the auditory tests the experimenter read the selection slowly, and the observer immediately reproduced the substance in writing.

The variation in the rates of reading for the different subjects led to the adoption of the number of words retained per second of reading-time, as the basis for determining ranks. In checking the materials, all errors in the reproduction were crossed out, and credit was then given for the number of words correct, calculating the per cent. on the basis of the number of words in the original. The advisability of scoring by the number of ideas recalled was considered, but a careful study of several reproductions showed that for the immediate retention of shorter selections, at least, the number of words reproduced is probably as accurate an estimate of an observer's performance as is the number of ideas.

Disconnected Material for Mediate Retention

This material, as that for immediate memory, was presented on the kymograph. The subjects were ranked for each method of presentation according to the average number of repetitions required by each to learn four series of ten units of the different types of material. In allowing for errors, one repetition was added for each substitution, omission or addition; one half repetition was added for each transposition; and one half repetition for each error of one letter in the nouns and syllables, and of one digit in the numbers.

Connected Material for Mediate Retention

These selections included, as for the immediate memory tests, one description, one narration and one exposition for each method of presentation. In the visual tests the observers read and re-read the selections silently and by the whole method until they were memorized for a written reproduction; the time required was noted by the experimenter while the number of repetitions was recorded by the observer. In the auditory presentation the selection was repeatedly read by the experimenter until the observer signified that he had memorized the production. The scoring of this material presented great difficulty, and the results are not very satisfactory for comparative purposes. Despite the earnest cooperation of the subjects, and the careful instructions given them to learn the material for a written verbal reproduction, underlearning was the result in many cases. The number of errors made as well as the learning-time required by the different subjects were so variable as to make it manifestly impossible to use either time required, or errors made, alone, as a basis for ranking; a penalization for errors was clearly necessary. Equally difficult material was selected, and five of the subjects repeated part or all of the tests; a comparison of the first and second performance showed that an addition of ten seconds of time for each error would be sufficient on the average to account for the improvement shown, and this amount was therefore added to determine the ranks.

Memory for Faces

Three series of photos, two of women, and one of men, each containing approximately fifty faces, were selected as material; ten of the first series were exposed to the observer for thirty seconds and then mixed with the entire list; after an interval of five minutes the observer was directed to identify the ten faces previously exposed. In the second and third series the procedure was the same, except that the intervals were respectively ten and fifteen minutes.

In scoring, the number of faces correctly identified as compared with the number exposed gave the per cent. from which the ranks were determined.

Ranks

From the gross results discussed above, the ranks of the individuals in the various tests were determined. They appear in Table I. The ranks in immediate memory for

Table I

Ranks

	Immediate Memory									Mediate Memory							
	Visual					Auditory				Visual				Auditory			
	Non-syl.	Numbers	Nouns	Prose	Faces	Syllable	Numbers	Nouns	Prose	Syllable	Numbers	Nouns	Prose	Syllable	Numbers	Nouns	Prose
A	6	3½	3	2	4	3½	5½	2	7	2	7	2	6	1	6½	2	3
B	1½	5	7	7	7	3½	4	7	4½	3	3½	1	5	3	3	4	5
C	5	9	5	3	1	7	9	6	1	5	2	4	2	6	2	5½	1
D	4	1½	1	1	2	1	1	1	6	1	3½	3	1	2	6½	1	6
E	8	8	4	6	4	5	7½	3	4½	6	8	7½	4	9	8	3	2
F	3	6	8	5	9	8	7½	9	2	9	9	8	7	8	9	9	7
G	7	1½	6	8	8	6	5½	4½	8	4	5½	6	9	4	5	5½	9
H	9	7	9	4	6	9	2½	8	3	7	1	5	3	5	1	7	4
I	1½	3½	2	9	4	2	2½	4½	9	8	5½	7½	8	7	4	8	8

nonsense syllables, numbers, and nouns are based on the per cent. retained. The ranks in immediate memory for prose are based on the number of words retained per second of reading time for the three types of prose combined. For reasons stated above, it was found to be impossible to obtain a fair ranking on a basis of the amount retained without reference to the time of reading. The rank for memory for faces is based on the scores for the three intervals combined. The ranks are determined directly from the results referred to above. The ranks for mediate memory for prose are based on the time for learning for the three prose selections plus ten seconds for each error.

Correlations

The coefficients of correlation, calculated by the formula

$$r = 1 - \frac{6\Sigma D^2}{n(n^2 - 1)}$$

from the above table of ranks, appear in Table II.

TABLE II

CORRELATIONS

		Immediate									Mediate								
		Visual					Auditory				Visual					Auditory			
		Syllable	Numbers	Nouns	Prose	Faces	Syllable	Numbers	Nouns	Prose	Syllable	Numbers	Nouns	Prose	Faces	Syllable	Numbers	Nouns	Prose
Immediate Visual	Syllables		.28	.25	−.24	−.01	.51	.27	−.01	−.13	−.01	−.14	.20	−.20	.06	−.03	−.17	−.37	0
	Numbers	.28		.44	−.07	−.02	.62	.62	.50	−.78	.08	−.10	.25	−.37	.61	−.20	.28	−.72	.11
	Nouns	.25	.44		.20	.70	.85	.28	.88	−.57	.45	.02	.22	.13	.25	−.28	.56	.08	.28
	Prose	−.24	−.07	.20		.52	.02	.03	.31	.40	.47	.33	.51	.76	.45	−.09	.53	.56	.29
	Faces	−.01	−.02	.70	.52		.43	.07	.60	.05	.40	.38	.33	.67	.15	.22	.51	.58	.35
Immediate Auditory	Syllables	.51	.62	.85	.02	.43		.52	.75	−.66	.56	−.08	.38	.03	.42	−.18	.58	−.19	.29
	Numbers	−.27	.62	.28	.03	.07	.52		.32	−.50	.45	.40	.37	.12	.48	.26	.24	−.39	.22
	Nouns	−.01	.50	.88	.31	.60	.75	.32		−.63	.67	−.13	.29	.18	.43	−.30	.81	.10	.30
	Prose	−.13	−.78	−.57	.40	.05	−.66	−.50	−.63		−.25	.24	.08	.54	−.33	.10	−.21	.58	−.04
Mediate Visual	Syllables	−.01	.48	.45	.47	.40	.56	.45	.67	−.25		.26	.83	.35	.85	.03	.90	.16	.41
	Numbers	−.14	−.10	.02	.23	.38	−.08	.40	.40	−.13	.26		.53	.57	.36	.90	.08	.23	.23
	Nouns	.20	.25	.22	.51	.33	.38	.37	.29	.08	.83	.53		.45	.86	.34	.66	.37	.42
	Prose	−.20	−.37	.13	.76	.67	−.03	.12	.18	.54	.35	.57	.45		.20	.25	.48	.67	.30
Mediate Auditory	Syllables	.06	.61	.25	.45	.15	.42	.48	.43	−.33	.85	.36	.86	.20		.23	.62	−.05	.35
	Numbers	−.03	−.20	−.28	−.09	.22	.19	.26	−.30	.14	.03	.90	.34	.25	.23		−.17	.28	.09
	Nouns	−.17	.28	.56	.53	.51	.58	.24	.81	−.21	.90	.08	.66	.48	.62	−.17		.38	.38
	Prose	−.37	−.72	.08	.56	.58	−.19	−.39	.10	.58	.16	.23	.37	.67	−.05	.28	.38		.14
	Average	0	.11	.28	.29	.35	.29	.22	.30	−.04	.41	.23	.42	.30	.35	.09	.38	.14	

With the small number of cases the probable errors of the coefficients are necessarily high, as can be determined by the formula,

$$P, E(r) = \pm .706 \frac{\sqrt{1 - r^2}}{\sqrt{n}}.$$

It was manifestly impossible to carry out such detailed experiments as these with the number of individuals necessary to bring the coefficients within the standard reliability limits, and the conclusions drawn in this paper are stated with an appreciation of this fact.

The table at first glance shows an astonishing confusion and variability. A closer inspection reveals, however, some interesting results. Taking each of the seventeen sets of correlations seriatim before considering the amalgamated correlations, it is at once evident that immediate retention of syllables presented visually shows no correlation worth noting with any other memory function, except that for immediate memory for syllables presented auditorily. It is then clear that immediate visual memory for syllables can not be used as a test of memorial efficiency. The immediate auditory memory for syllables shows higher correlations, but even it is an index of memorial efficiency only for disconnected materials.

Immediate visual memory for numbers correlates fairly well with immediate and mediate disconnected material, except in the case of mediate memory for numbers where curiously enough it is negative; the average correlation with prose is −.49. Immediate visual numbers correlate fairly well with disconnected materials, while the correlations with prose average −.18. Immediate auditory memory for numbers is then a better index of memorial efficiency than is immediate visual memory for numbers.

Immediate visual and immediate auditory memory for nouns shows higher average correlations than either the syllables or numbers, and are therefore a better memory test; even here, however, the correlation of the visual with prose is −.04, and of the auditory with prose −.01.

Immediate visual memory for prose shows a rather high

correlation with mediate memory for all types of material except auditory numbers; the correlation is also high with faces and immediate memory for nouns and auditory prose, but low with all the numbers and syllables.

Immediate auditory prose correlates well with other types of prose, but shows very little correlation with other functions of memory here tested; the average correlation with the other tests is −.04.

Faces show a higher average correlation than any type of immediate disconnected material, and are apparently especially good as an index of ability to learn nouns, mediate prose, and immediate visual prose.

Mediate visual memory for syllables shows an average correlation of .41 with all the other memories tested, though its average correlation with prose is only .19. Mediate auditory syllables show a lower general correlation, and the average correlation with prose is only .07.

Mediate visual memory for nouns shows an average correlation with other memory functions of .42; the correlation with prose is .35. Mediate auditory memory for nouns shows an average correlation with other memories of .38; the correlation with prose is .30. The learning of visual nouns is then a fair index of general memory, and of ability to learn prose which constitutes much of our learning.

Mediate visual memory for numbers shows a general correlation of .23, and a correlation with prose of .32; the average correlation with immediate materials is low. Mediate auditory memory for numbers shows an average correlation of only .09; the correlation with prose is .15. Visual numbers are therefore a better memory test than auditory numbers.

Mediate visual memory for prose has a correlation of .30 with other materials; mediate auditory memory has a correlation of only .14. Each correlates loosely with all immediate materials except faces, and the other presentation of prose; the lowest correlation with mediate material is that with syllables.

An inspection of the average correlations shows that of

disconnected materials, mediate visual nouns is the best index of general memory; mediate visual syllables is second best; mediate auditory nouns ranks third; mediate auditory syllables and faces rank together, fourth; mediate visual prose and immediate auditory nouns rank next; immediate syllables and immediate auditory prose follow. If both methods of presentation are employed for both types of learning, the numbers are the least accurate of the materials through which to determine efficiency in general while the prose is but little superior.

Correlations in Immediate and Mediate Retention with Presentations Pooled

There is a correlation of $-.24$ between the average ranks of the observers in immediate memory for the three types of disconnected materials with both visual and auditory presentations, and the average ranks for mediate prose with both presentations.

There is a positive correlation of .33 between the immediate retention for disconnected materials and the mediate retention for disconnected materials and prose amalgamated.

The immediate disconnected materials and the mediate disconnected materials show a correlation of .50.

Immediate memory for the different types of materials and mediate memory for the same show a correlation of .52.

The ranks in retention for immediate connected material and mediate connected material show the high correlation of .73.

These results show that there is a rather high correlation between immediate retention and mediate retention. Any single test of immediate memory correlates but loosely with mediate memory, but when a sufficient number and variety of measurements are given the amalgamated rank is a fairly good index of ability to memorize. Tests for immediate memory of disconnected material do not correlate as highly with mediate memory of the connected and disconnected material, and are not as useful an index of learning capacity. This dependence of the correlation on the type of material

is brought out strikingly when we find an inverse correlation between immediate memory for syllables, numbers and nouns, and the capacity to learn connected discourse. The immediate memory for syllables, numbers and nouns correlates rather highly with the ability to learn the same materials; the coefficient is .50.

The highest correlation of the five discussed is between the immediate and the mediate learning of prose, *i. e.*, a memory function which has run parallel with comprehension and apperception is closely correlated with verbal learning.

The general result is clear. When the statement is made that there is little or no correlation between the memory span and ability to learn, the proposition is true only when we compare immediate memory for disconnected material with the learning of connected discourse. The immediate memory for disconnected materials, such as syllables, numbers and nouns, is correlated highly with the ability to learn the same type of materials. The immediate retention of connected discourse is correlated very highly with the ability to learn such material.

Disconnected Materials and Prose

There is an inverse correlation of −.27 between immediate memory for syllables and prose, and an inverse correlation of −.48 between immediate memory for numbers and prose.

Mediate memory for syllables and prose shows a correlation of .11, while mediate memory for numbers and prose shows .27. The correlations are low for both, showing the dependence of the adult on meaning even in verbal learning.

The immediate memory for nouns and prose shows a correlation of −.23, while the mediate memory for the same shows a correlation of .36. We find a correlation of .33 between the mediate learning of disconnected materials amalgamated and the immediate and mediate retention of prose amalgamated.

The correlation between the learning of all the disconnected materials and all the connected materials is an inverse one of −.01.

The memory span for numbers, nonsense syllables and nouns, seems then to have a negative correlation to immediate memory for prose, the type of learning in which the adult is most interested. No amalgamation of immediate and mediate learning of disconnected materials seems to give an index to the ability to retain prose. The mediate learning of disconnected material is a far more accurate measure of the mastery of connected discourse, but this correlation is only .33.

Correlations in Mediate and Immediate Memory with Visual Presentations and with Auditory Presentations

The highest of the correlations, .92, is between the auditory and visual presentation of mediate disconnected material. The corresponding correlation for immediate disconnected material is .82; for mediate connected .67; for immediate connected .40. From this it appears that the auditory and visual presentations of disconnected materials correlate more highly than the same presentations of connected materials; also that mediate learning has higher correlations than immediate.

The immediate disconnected material, when compared with immediate prose shows correlations varying from .05 to −.74; when compared with mediate prose the correlations vary from .07 to −.47.

The mediate and immediate learning of the same types of material shows correlations ranging from .42 to .73; the correlations between the connected materials are higher than those between the disconnected.

Correlations between the mediate learning of prose and the mediate learning of disconnected material show a range from .20 to .54.

The immediate learning of prose presented visually shows a correlation of .49 with the mediate learning of disconnected material presented visually, and a correlation of .60 with the mediate learning of disconnected material presented auditorily. The immediate learning of prose presented auditorily shows a correlation of −.16 with the mediate learning of

disconnected material presented auditorily, and a correlation of −.08 with the mediate learning of disconnected material presented visually.

Visual and Auditory Presentation. The Last General Problem on which These Results Throw Light, is the Correlation between Visual and Auditory Presentations

The correlations are .80 for the immediate learning by the different presentations and .75 for the mediate learning; the correlations between the mediate and the immediate memory are about half as much, averaging .37. The correlations, therefore, between the different presentations within the same type of learning are positive and very high.

Relative Values of Visual and Auditory Presentations

A comparison of the immediate retention with visual presentation and the immediate retention with auditory presentation shows very slight differences. The average number of units retained out of 222 with disconnected materials were: Visual, 173.9; auditory, 175.8. It is noteworthy, however, that the memory span, or immediate memory for disconnected materials is 76.7 per cent. with auditory presentation and only 71.2 per cent. with visual. The average number of words per second of reading time retained in immediate memory for prose were, with visual presentation 1.35 and with auditory presentation 1.38.

The average number of repetitions for learning syllables, numbers, and nouns with visual presentation is 6.9, while with auditory presentation is 7.4. The mediate learning of prose with visual presentation gave an average time of 31.4 minutes, while for auditory presentation it was 32.5 minutes.

Individual Differences

Many striking individual differences are disclosed. The most noteworthy will be enumerated.

1. Contrary to expectations in the immediate retention of prose all but two subjects, *A* and *D*, showed a higher efficiency from auditory presentation than from visual.

Table III. gives the results, calculated on a basis of number of words per second retained.

TABLE III

IMMEDIATE MEMORY FOR PROSE (WORDS PER SECOND)

	Vis.	Aud.
A	1.73	1.408
B	1.25	1.44
C	1.5	1.54
D	1.88	1.42
E	1.258	1.44
F	1.26	1.47
G	.965	1.225
H	1.38	1.45
I	.912	1.03
Average	1.35	1.38

Subject *D* is very dominantly visual in type but retains better from auditory presentation.

The same two subjects showed a higher efficiency with auditory presentation of disconnected materials also.

TABLE IV

IMMEDIATE MEMORY FOR DISCONNECTED MATERIALS

	Vis.	Aud.
A	180	182.5
B	178	174
C	166.5	168.5
D	189.5	190
E	167	177.5
F	170.5	160.5
G	171.5	178.5
H	154	168
I	188.5	184
Average	173.9	175.8

2. While there is a positive and fairly high correlation between the memory-span and ability to learn, there are three very marked cases, subjects *C*, *H*, and *I; C* ranks 7 in memory-span for disconnected materials and 1 in learning and immediate retention of prose; *H* ranks 9 in memory-span and 2½ in the tests with prose, while *I* ranks 2 in memory-span and 8½ with prose. It is these three cases that produce the very low correlation, −.30 between memory-span and the learning and retention of prose. The differences in ranks

with the other observers are slight. In other words but three of the observers out of nine show the lack of correlation which Meumann regards as the rule.

3. A striking difference between the observers was found in the feeling of certainty that the materials had been learned and the relation between this judgment and its accuracy. This became a source of great difficulty in determining the ranks in the learning of connected discourse. In no case could an errorless reproduction be given but the variability in number of errors was very great ranging from 1 by subject *D* in visual exposition, to 46 by subject *H* in auditory narration.

4. As to the relation between the accuracy of learning prose and the time required to learn, we cannot say that the slow learners are the most accurate or vice versa. *F* who gave the most accurate reproductions in the pooled results was comparatively slow; *D*, the most accurate in reproducing from visual presentation, learned rapidly; *G* learned slowly and made numerous errors in reproducing; *C*, a rapid learner, made fewer errors than some of the slower learners. These differences would indicate that there is no necessary relation of time and accuracy in mediate learning of prose.

Conclusions

1. Nouns presented visually for mediate learning show the highest of the correlations with the other memory functions tested and seem, therefore, to be the best index of general memorial efficiency; mediate syllables presented visually afford the second highest correlation.

2. There is a high correlation between mediate and immediate retention if a sufficient number and variety of measurements for each type of memory are taken, and the results amalgamated to determine ranks.

3. There is a high correlation between the memory span, or immediate retention for disconnected materials, and the ability to learn the same.

4. Six of the nine observers showed a high correlation between the memory-span and the pooled mediate and im-

mediate learning of prose; three subjects, two of whom are sisters, occupied great enough differences in ranks to make the average correlation inverse. The conclusion would seem to be that for the majority of individuals there is a high correlation between the memory-span and the ability to master prose.

5. Mediate retention shows higher intercorrelations than immediate retention.

6. Disconnected material for mediate retention shows higher correlations than does connected material.

7. The correlations between the mediate learning of connected materials, and the immediate learning of the same are higher than the corresponding correlations for disconnected materials.

8. The auditory presentation showed slightly better results for the immediate retention of both disconnected materials and prose.

9. The immediate retention of nonsense syllables was better with auditory presentation than with visual.

10. The mediate learning of both connected and disconnected materials was slightly better with visual presentation.

11. The correlations between the visual and auditory presentations within the same type of material are very high.

12. There seems to be no relation between the speed of learners and the accuracy of their performances.

THE EFFECT ON FOVEAL VISION OF BRIGHT SURROUNDINGS—III

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In previous reports of work on this subject under similar title (1, 2) it was intimated that the results there given relating to the brightness-difference threshold lacked in definiteness, the reason for this being in part at least due to the form of apparatus used to furnish the test-stimuli. The purpose of the present paper is to describe a modification of the apparatus used, by which those defects were overcome. The results obtained by the latter are to be the subject of a subsequent communication.

Reference to the first of the series will show that the results so far reported were obtained by the use of a differential method. The two halves of the test-field to be judged by the observer were parts of two illuminated milk-glasses thrown into visual juxtaposition by means of a double prism. The difference in brightness of these two was brought about by shifting one of them so as to alter its distance from the actual or virtual source of light, the other remaining stationary. The areas of the glasses used were rather large and there is always difficulty in securing uniformity of such transmitting media. Further, there is difficulty in securing uniform illumination over such areas. There was therefore no positive assurance that the brightness-difference across the line of division between the halves of the field was equal at all parts of that line, or that the separate halves of the field were each of uniform brightness. And finally, there was no positive way of knowing exactly when that difference was zero. There are still other ways in which the method has been improved which will be mentioned later.

The essential differences may be described at the outset. One is that the new method is additive, not differential.

That is, the difference between the two halves of the field is obtained by superposing an additional brightness upon one half of a constantly visible field of uniform brightness. This is brought about by partial reflection from a plate glass surface, and readily permits of independent measurement of the field brightness and of that of the added difference; which is a distinct advance over the photometric procedure of measuring the difference as such.

The second change consists in the projection of the test-field by a lens. This makes it possible to locate the image (which is the thing actually observed) at any distance from

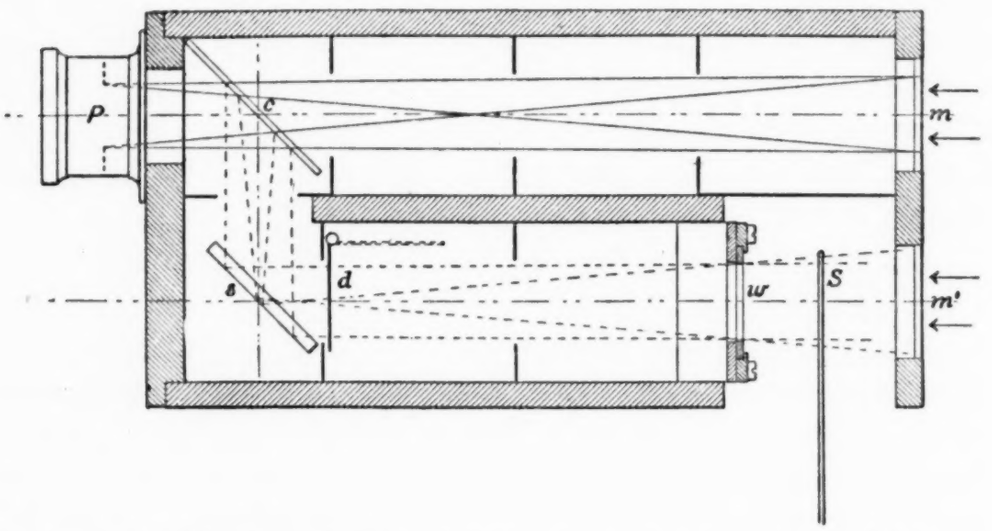

FIG. 1. Device for projecting test field and secondary image adding brightness to one half.

the observer. As a matter of fact it is at present placed in the plane of those parts of the surroundings which lie adjacent to it, making it easy and natural for him to accommodate accurately for it.

Reference to the figures will make clear how this is done. Fig. 1 represents the part embodying the principal change in the apparatus. It is simply a camera with its lens at *P*, by which an image of the milk-glass *m* is projected at some point on the other side of *P*. A second milk-glass *m'*, illuminated by the same source as *m* is so placed as to fill a small window *w* as seen from any part of the lens-aperture at *P* by its light reflected once from the silvered mirror *s* and

again from the clear plate glass *c*. The result is that at some point beyond *P* there are two images; one of *m*, the light from it having suffered a minor loss in passing through the clear glass *c*, the other resulting from reflection at *s* and *c* and being an image of the window *w*. The two paths *mP* and *wscP* being made equal and the two mirrors being properly adjusted the images of *m* and *w* will coincide. It is to be noted that the latter of these two paths is possible owing to partial reflection at *c*, the reflection at *s* being not far from complete; while in the case of the former the path is direct with a small loss by transmission through *c*. The result is that the two images are of unequal brightness. With

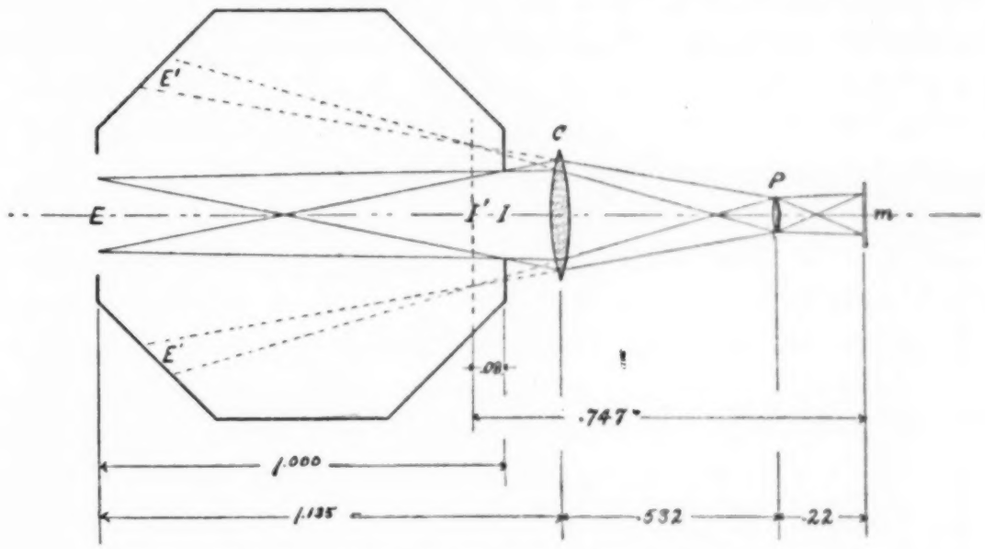

FIG. 2. The optical system and its principal dimensions (meters).

equal illumination on *m* and *m'* the brightness of the image of the window *w* is about 8 per cent. of that of the image of *m*.

The window is provided with a shutter which may be slid sidewise to the extent of half its (horizontal) length, thereby cutting off half of its image, the other half being unobstructed is superposed on the image of *m* and brings about a measurable difference of brightness in the two halves of the field, which by sliding the shutter one way or the other may be made an increment to one half or the other. The exposure is made by a door situated at *d*, in the path

of the light from *w*, which when closed cuts off the addition, leaving the field of uniform brightness.

The brightness of the surroundings is controlled as in the previous work (1) as indicated in Fig. 3. The principle of the optical system is shown diagrammatically in Fig. 2, where the transverse dimensions are exaggerated five-fold for the sake of clearness. The image from the camera would without further provision fall at I' and viewed directly by an eye placed at E much of the light would be lost since, to illustrate, the light from the extremes of the image would fall at $E'E'$ and not enter the eye at all. The result would be that the image would be seen limited by the aperture of P. This is obviated by the use of a condensing lens at C by which the image of the aperture P is brought to a focus upon

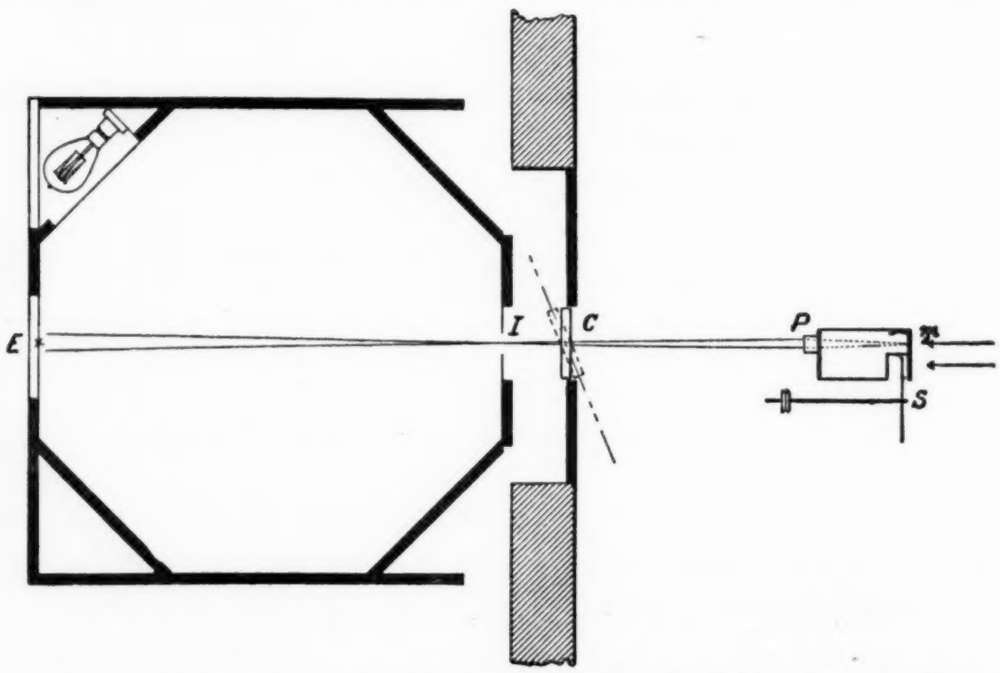

FIG. 3. General arrangement of apparatus. The test field is seen at I by the eye at E, surrounded by the illuminated inner surface of the polyhedral chamber E–I.

the eye, all the light from the image I falling within the circle thus formed. It will be seen from the figure to be a consequence of this that light from any part of I reaches the eye, diverging as it does so, exactly as though it came from a solid diffusing surface, provided that the eye be placed within

the image E; and that no light whatever from I falls anywhere else. This accomplishes the control of the field-brightness independently of that of the surroundings.

It is to be noted that the limiting edge of the field is the edge of the opening I in the surface forming the surroundings. As a matter of fact it is only necessary that the image of the intercepting edge of the window at w be in focus in this place provided the milk-glasses m and m' be large enough to intercept every possible optical path through the opening I and the aperture P. The latter (m') is some 5 cm. from w and is large enough to fulfil this condition, and m being of the same size and nearly in focus is necessarily adequate.

Both mirrors, c and s, Fig. 1, had to be selected so that the double reflection in each case gave apparent coincidence of the vertical lines in the two images. Commercial plate glass was used, of which the sides are rarely quite parallel, but by careful examination the proper axis is readily found and the piece for use cut accordingly. Double reflection also results in slightly different lengths of path $wscP$, Fig. 1, but when the mirrors are selected as just said the several images of the edge intercepting all intersect the visual axis but at slightly different distances from the observer's eye. Monocular vision is used and under these circumstances this does not occasion any disturbance whatever.

P is a photographic lens of a fair grade having a focal length of 16.7 cm. and used with an aperture of 17 mm. C is a reading glass of the usual type 15 cm. in diameter and having a focal length of 37 cm. It is inclined as shown in Fig. 3 to avoid the reflection of light emerging through the opening I back into the eye of the observer at E. This does not occasion distortion of the image of the vertical intercepting edge of w since the latter in the position used during observation intersects the axis of the system.

The opening at I is 3.4 by 4.6 cm. Its projection at m and at w is 1.6 by 2.2 cm. The window w is somewhat larger than this, especially in its vertical dimension to allow for the overlapping of the double images. The milk-glasses m and m' are 3 by 4 cm. Other dimensions are given in Fig. 2.

The brightness of the addition to one half of the field is cut down by a variable sector disc mounted on a rotator of the Lummer-Brodhun design, originally intended for the rotation of paper color-discs. In place of the latter two sectors of black cardboard are used, each with two openings of 90°. This gives a maximum opening of 180° which may be reduced to 0 or set at any intermediate point while the sector is in rotation. The rotator is placed as shown in Fig. 3 with the edge of the sector at *S*, Fig. 1. The maximum addition possible is therefore about 4 per cent. with this arrangement, that is, half of that found with the sector removed. When under certain conditions this is insufficient a smoke glass is placed in the path *mP* and the illumination increased to compensate. The addition is then greater for the same brightness of field.

The illumination of the field as indicated by the arrows in the figures is from a source to the right of *m* and *m'*, which lights them both at once. A 500-watt tungsten filament vacuum lamp rated at 115 volts is enclosed in a cubical tin box painted white inside with a milk glass window 20 by 20 cm. in one side. The lamp is run at 87 volts since at that voltage a color match between the field and its surroundings is obtained. The latter are as previously described (1), lighted with lamps of the same type run at normal voltage, the necessity for the difference in running voltage arising chiefly from differences in selective reflection and transmission of the media which play parts in the two cases.

The photometric measurements are made with a Beckstein portable photometer calibrated against a surface of known brightness, by forming an image of the field in the plane of the photometer and so measuring the brightness directly. The field-brightness and the addition are measured separately by stopping one or the other path in the camera, the latter with the light unobstructed by the sector. This gives a ratio from which the ratio with any given sector-opening may easily be computed.

The various brightnesses of the surroundings are first measured relatively to one another in an exactly similar way.

Owing to the fact that their larger extent caused a larger amount of light to be scattered within the photometer their absolute brightness is computed from that of one of the series; which is obtained by first equating surroundings and field by means of the photometer, then darkening the surroundings and measuring the unchanged field as before.

The lamps are all on one circuit supplied by a storage battery and the voltage is accurately checked in the course of observation. The exposure is controlled electrically by a pendulum which automatically limits it to a predetermined interval. It is initiated by the observer through a key, and results from the opening of a small door *d*, Fig. 1, as indicated. The observer's eye is thus exposed to the uniformly bright field up to the instant the door admits the additional light to one half and the experiment begins.

The advantages of this arrangement over the one previously described are in brief:

1. The small extent of diffusing medium necessary to form the image decreases the magnitude of both the inequalities in its properties and those of its illumination. With the addition cut off it is not possible to detect difference in different parts of the field even with the photometer.

2. The point of equality of the two halves of the field (or at least a fixed reference-point) is therefore established in the physical sense when no addition is permitted to either half of the field.

3. The method used permits the measurement of the difference separately and directly, which is a decided gain in accuracy over its measurement *as* a difference.

References

1. Cobb and Geissler. *Psychological Review*, XX., pp. 425–447, 1913.
2. Cobb. *Ibid.*, XXI., pp. 23–32, 1914.

ON COLOR INDUCTION WITH REFERENCE TO COLOR RECOGNITION

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I

The Problem.—The precise nature of after-images of all sorts and their exact rôle in the determination of sensational and representational states of consciousness subsequent to the appearance of these after-images, remain, in spite of the enormous literature, clouded in doubt and surrounded by controversy. The interminable nature of the primary stimulus, the leakage of light through the sclerotic and iris coats of the eye, the varying sensitivity of the retina bring about the greatest diversity in the visual after-image. These relatively uncontrollable influences combine to make the after-effects of the primary stimulations very uncertain even for a particular observation or series of observations made in a given time, so that the features of after-images are, perhaps, as well characterized by their differences as their likenesses.

From the above it follows that the after-effects of a primary stimulation will affect a secondary stimulation recognizably different at different times. The lack of constancy here, not only in the primary stimulus but in the secondary as well, becomes an important source of error, as will be seen below.

The rôle of the after-image in the general economy of human behavior is wrapped in quite as much uncertainty as the character of the image itself. James[2] expressed the opinion that "we shall probably never know just what part retinal after-images play in determining the train of our thoughts. Judging by my own experiences I should suspect it of being not insignificant." From the large number of cases cited in this reference, it is obvious that the function,

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[2] 'Principles,' Vol. II, p. 84.

as well as the nature of the after-effects of stimulation is enveloped in considerable obscurity.

The nature of the after-effects of primary stimulation has long been an object of investigation but relatively little intensive work has been done on the influence of such effects on subsequent stimulation. A quantitative determination of the effects of negative after-images upon the threshold values for secondary color stimulations seems not to have been systematically undertaken. The purpose of the present study[1] is (1) to determine the limens of sensitivity for the commonly denominated primary colors when mixed with black and (2) to determine the limens of sensitivity for each of the same colors after adaptation to (*a*) blue, (*b*) yellow, (*c*) green and (*d*) red. With reference to the influence of adaptation, our problem is, by *how much* does the color and brightness of one stimulus affect the color and brightness of a second stimulus seen directly after it.

With reference to color recognition, Purkinje[2] observed that the primary colors were seen in their true tone as daylight advanced in the following order, blue, green, yellow and red. No limens for sensitivity were determined. Aubert,[3] by varying the daylight illumination on colors 10 mm. square, found the following order of color sensitivity, orange, red, yellow, blue, green. In a later experiment he employed a Masson disc and increased the proportion of color mixed with gray. The order of recognition now changed to orange, yellow, green, red and blue. He found that a little less than two or three degrees of color were needed to determine the recognitive limens of the colors when mixed with black. These experiments do not agree with our results as to the order of sensitivity for the colors red, yellow, blue and green when mixed with black and without the influence of primary stimulation. Our results are confirmed by Raehlemann[4]

[1] An investigation of the recognitive limens for the four primary colors when (1) mixed with gray and (2) mixed with white will follow the present study.

[2] Purkinje, J., *Beiträge zur Kenntniss des Sehens*, 1825, II, p. 109.

[3] Aubert, H., 'Untersuchungen über die Sinnesthätigkeit der Netzhaut,' *Pogg. Annal.*, 1862, CXV., pp. 87–116. Aubert, H., 'Physiologie der Netzhaut,' pp. 138–150.

[4] Raehlmann, E., 'Über Schwellenwerte d. verschiedenen Spectralfarben an versch. Stellen d. Netzhaut. A.F.O.,' 1874, XX., pp. 232–254.

who, on increasing the intensity of light necessary to give a spectrum, found the recognitive order of sensitivity to be, green, yellow, blue, violet and red. These results are for the limens without the effects of primary stimulation. Geissler[1] determined the limenal saturation values for various colors for each eye separately and for both eyes. The limens for saturation do not follow the order as given by Aubert, Raehlmann and Bentz. For the most part these studies bear upon the recognitive limens for colors independent of the after-effects of primary stimulation.

The influence of after-effects of previous stimulation upon color-matches was studied by Buhler,[2] v. Kries,[3] Hering,[4] Tschermak,[5] Watson[6] and others. There seems to be general agreement that the values of color-matches remain undisturbed by after-effects of previous stimulation, especially (v. Kries) so far as these matches apply to foveal vision.

After-effects of various kinds of primary stimuli have received the attention of a large number of investigators. As early as 1743 Buffon[7] reported that the after-image of a color fused with the background of another color (secondary stimulation) in such a way as to form a third color. It is interesting that the determination of the recognitive limens of colorless and chromatic secondary stimuli as affected by after-images of primary stimuli received little attention. Investigators, for the most part, observed qualitative changes in sensations of secondary stimulation due to previous stimulation.[8]

II

The apparatus employed in this study consisted of a four-spindle color-mixer, an induction chamber, a modified Kühlmann time apparatus and a seconds pendulum.

[1] Geissler, L. R., 'Exp. on Color Saturation,' *Am. Jour. Psych.*, Vol. 24, pp. 171–179.

[2] Buhler, Dissert., University Freiburg, 1913.

[3] v. Kries, *Arch. f. Anat.*, 1878.

[4] Hering, *Arch. f. d. ges. Physiol.*, LIV., 1893.

[5] Tschermak, *Arch. f. d. ges. Physiol.*, 1898.

[6] Watson, *Proc. Roy. Soc. London*, 1913.

[7] Buffon, 'Dissert. sur les Couleurs Accidentelles,' Memoires de l'Acad. de Sciences de Paris, 1743, p. 213.

[8] Parsons, 'An Introduction to the Study of Color Vision,' pp. 105–112.

Four-Spindle Color-Mixer.[1]—The color-mixer, shown in Plates I., II., III., was equipped with an adjustable shutter *A*, with a micrometer screw attachment eight threads to the inch read on scale *B* in eighths of inches, and a hand drive *C* scaled to one hundred divisions for a full turn on *D*. Clutch *F* when set (*F'* in the phantom picture, Plate II.) secured the contact of wheel *E* (*E'* in Plate II.) with both wheel *G* attached to the motor *K*, and wheel *H* on the spider *O*. Wheel *M* on the same axis as wheel *H* was thus revolved when the clutch was set and the motor started. Special red, yellow, green, and blue color discs were held securely on the four wheels *M* of the spider by the thumb nuts *N*. (A full description of these discs is given below.) The photograph of the back of the apparatus (Plate III.) shows the method by which the revolving spider was made secure in each of the four positions by pin *P* extending through groove *R*. This enabled each of the discs to be brought into position for observation. A small shield *S* fitted over the adjustable shutter *A* in such a manner that on closure of the shutter the circular opening, as shown in the phantom picture, coincided with the circular opening in the shield. A large neutral gray shield *T*, which in the photograph appears below the apparatus, covered the entire front of the mixer, the small shield *S* being behind opening *V*.

Induction Chamber.—The dull black induction chamber was provided with interior lights. Two of these (16 c.p. each) indirectly illuminated sheets of paper eighteen inches square of the Milton Bradley standard red, blue, yellow and green. The end of the hood to the induction chamber was so shaped as to fit the face, thus excluding all other light stimuli.

Modified Kühlmann Time Apparatus.—Reference to the time apparatus, Plate IV., will make clear its mode of operation. As soon as the electromagnets became active, they attracted the armature 6, attached to the clutch 1. This

[1] This piece of apparatus was designed by Dr. A. P. Weiss, who kindly supervised the making of Plates I., II. and III. and who rendered other valuable technical assistance. A more complete account of this piece of apparatus will be published in the near future.

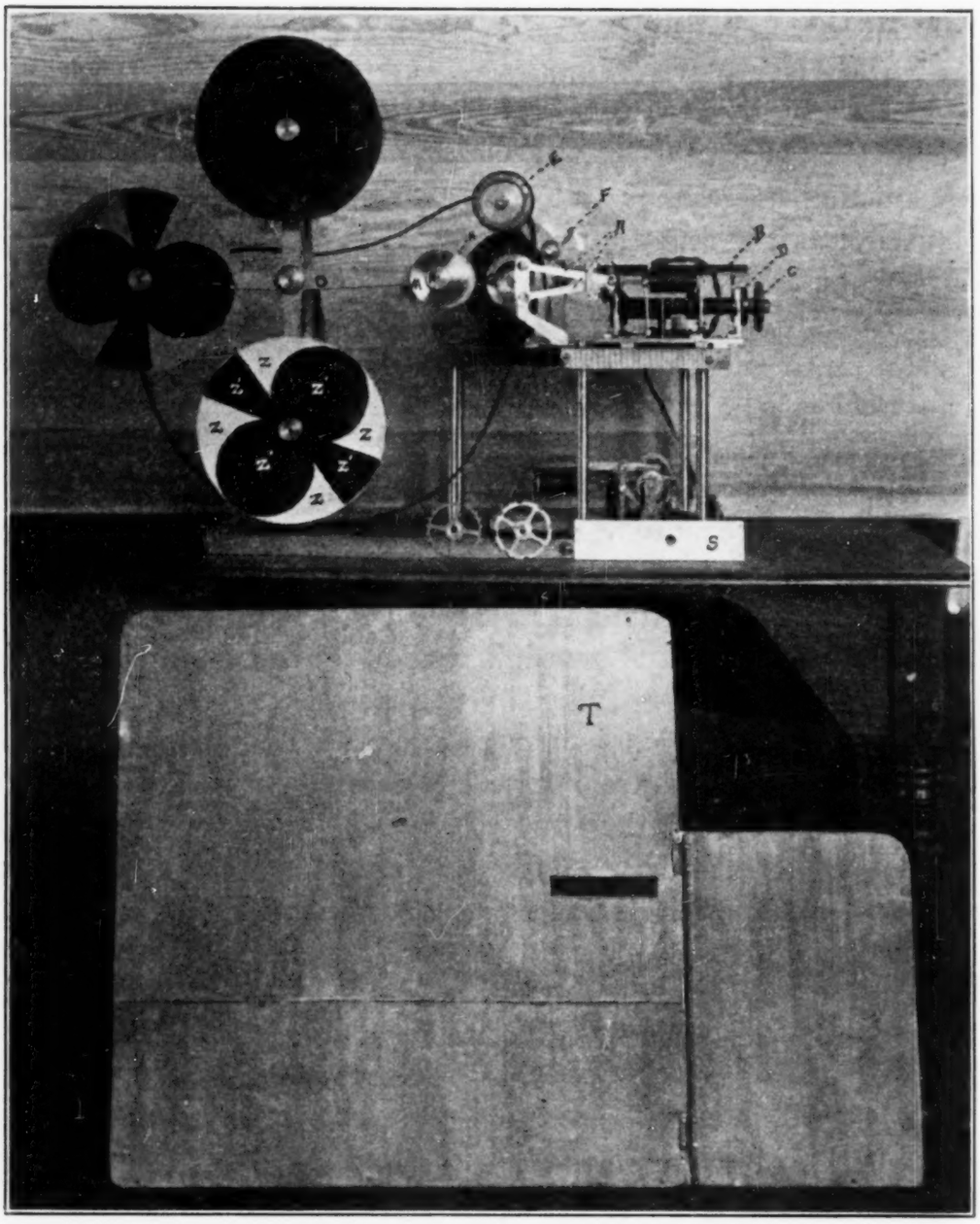

Plate I. Front View of Complex Color-mixer.

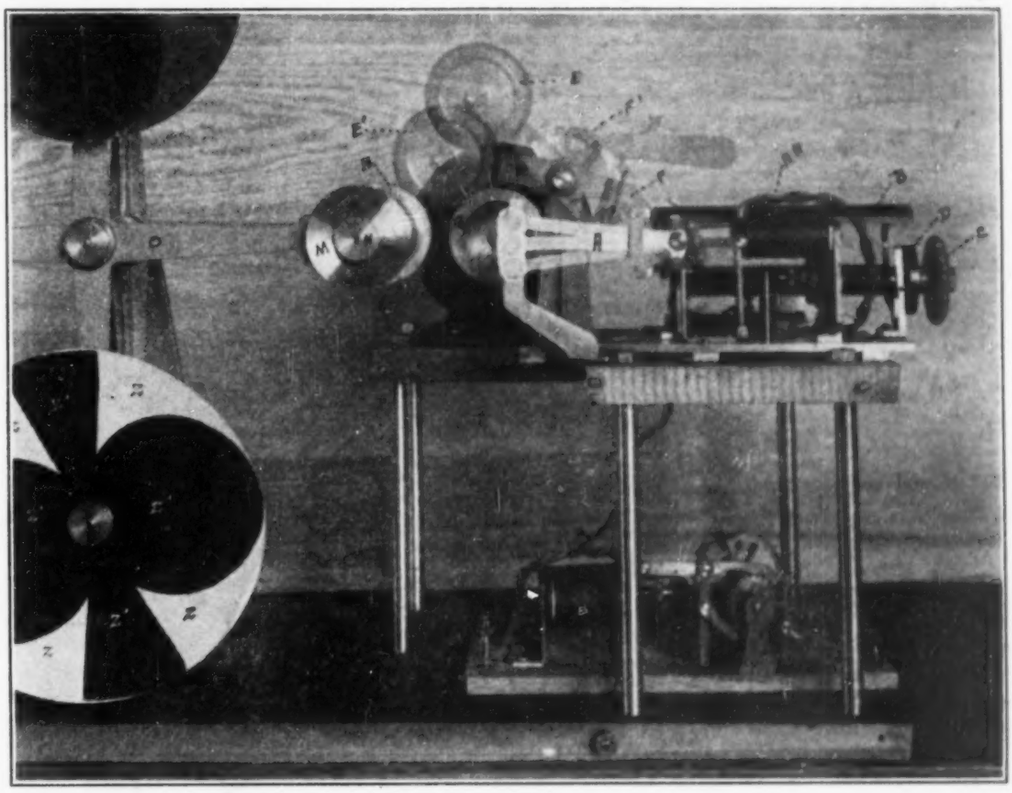

Plate II. Front View of Complex Color-mixer. Phantom Picture.

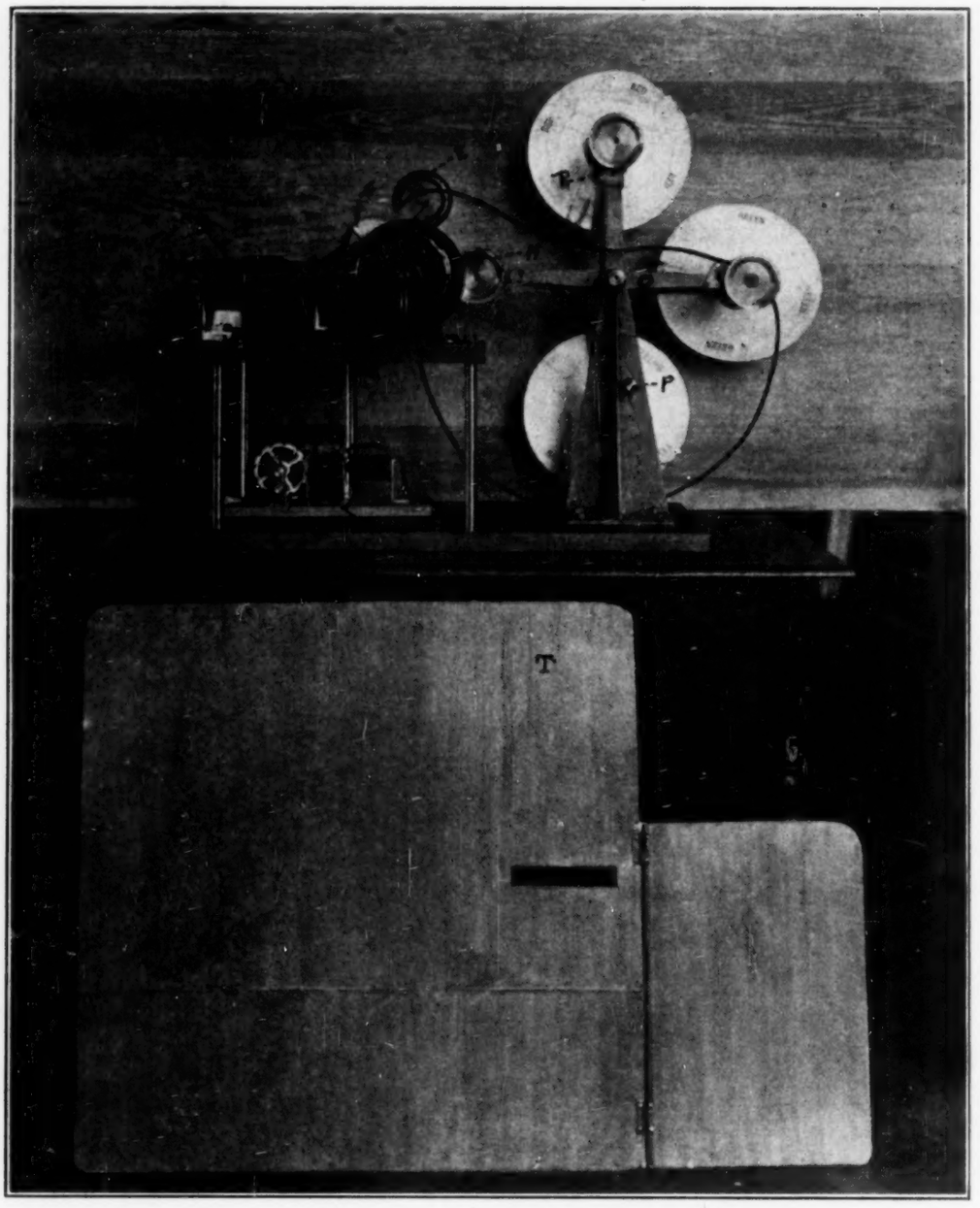

Plate III. Back View of Complex Color-mixer.

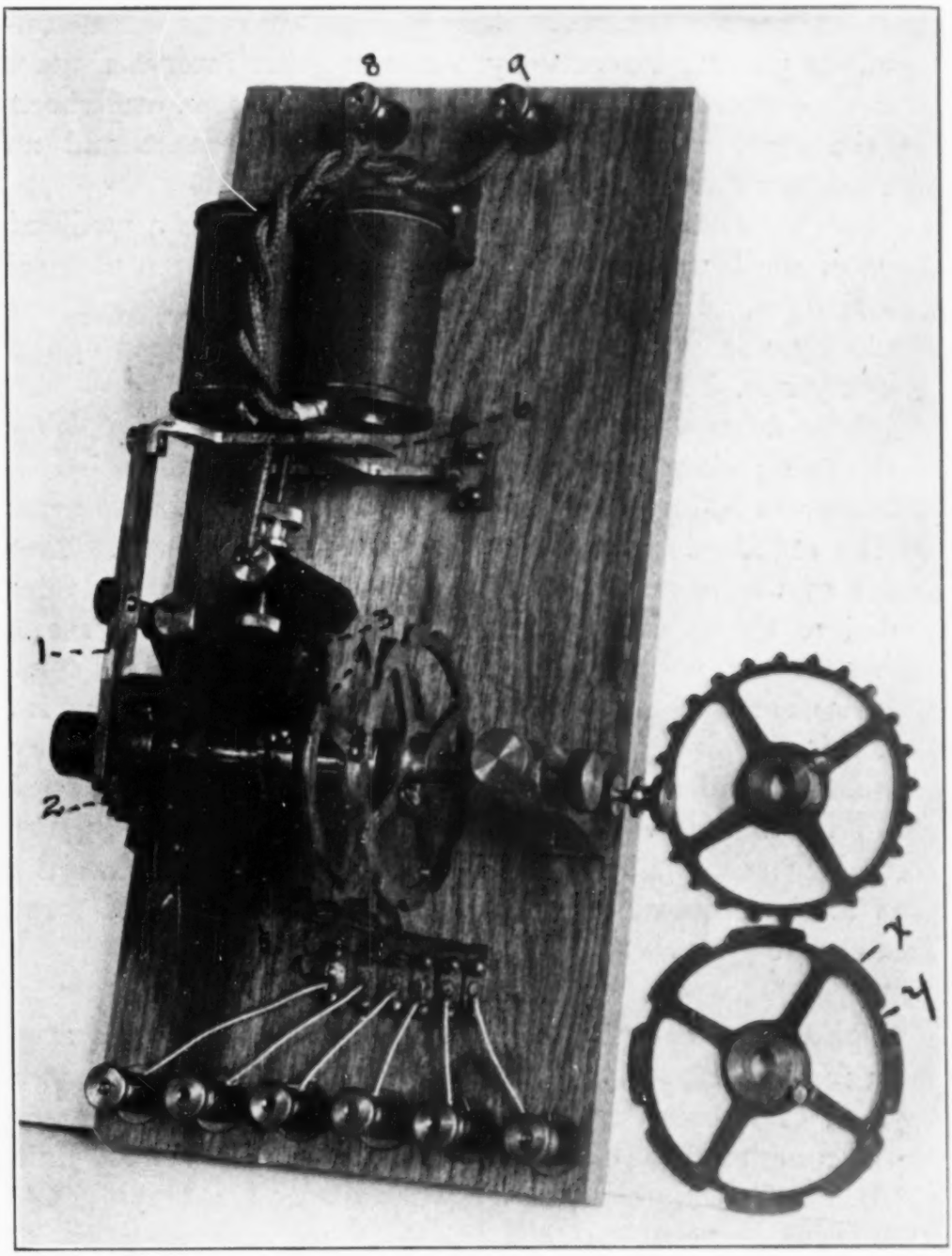

Plate IV. Modified Kühlmann Time Apparatus.

clutch fitted into the toothed wheel 2 and each attraction of the magnet pulled the wheel one notch forward. The two wheels, 3 and 4, on the same axis with wheel 2, were so cut that at certain intervals they formed contacts with connections 5 and 7 respectively, while at other intervals, there was no contact. *X* and *Y*, referring to the separate wheels at the right of the apparatus, designate contact and no contact respectively.

Seconds Pendulum.—The seconds pendulum is a modified form of similar pieces of apparatus common to psychological laboratories. In this particular pendulum the contact was made by the point of the pendulum swinging through a mercury cup.

Color Discs.—Special color discs were made by pasting overlapping black paper discs five and one eighth inches in diameter on Milton Bradley color discs ten inches in diameter of the standard colors blue, yellow, green and red. Two strips of the same black paper, of ten degrees each, were added to the color portion. The character of the discs is shown in the photographs (Plates I. and II.). The color portions are designated by *Z*, the added black strips by *Z'*.

Light Restriction Hood.—A specially devised hood of gray pasteboard and about eight inches in length was so shaped as to fit the face. This hood was used in observing the secondary stimuli, limiting the light that might affect the eyes to that coming from the shutter opening and adjacent area on the gray shield.

III

The manner of articulating the various pieces of apparatus is set forth in Plate V. When the circuit was closed through key, *K*, each contact of the pendulum *S* with the mercury cup 1, completed the circuit through posts 8 and 9 of the time apparatus *T*, thus causing the wheels 3 and 4 (Plate IV.), to revolve one notch at a time. Contact between wheel 3, and connection 5 completed the circuit through the color-mixer. The shutter *A* was then opened by actuation of the armature, to which it was attached, by the electro-magnets (*AA*, Plate II.). The circuit was made through the induc-

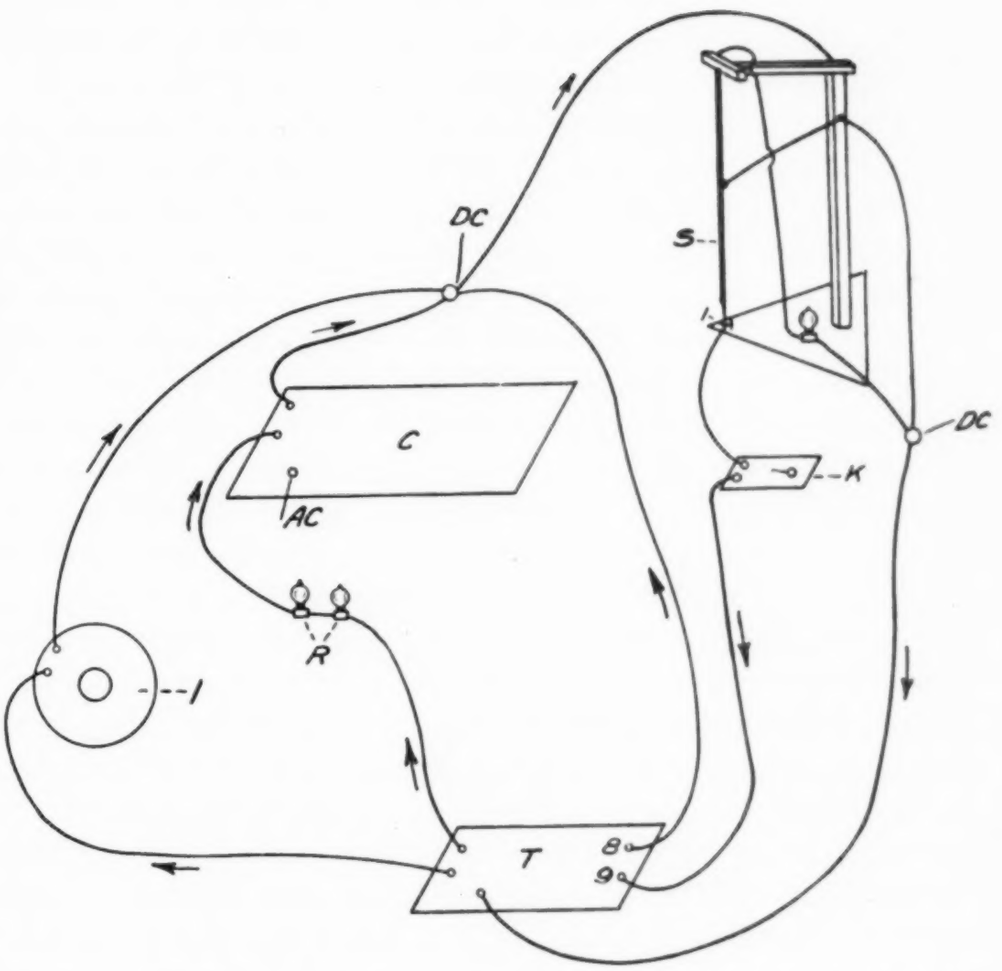

PLATE V. Diagrammatic Arrangement of Apparatus. *I*, Induction Chamber; *C*, Complex Color-mixer; *S*, Seconds-pendulum; *T*, Kühlmann Time Apparatus; *K*, Key; *DC*, Direct Current; *AC*, Alternating Current; *R*, Resistance.

tion chamber when wheel 4 came in contact with connection 7. This wheel (4) controlled the duration of the illumination of the inducing colors (primary stimuli). The motor was attached to an alternating current and controlled by a switch (*W*, Plate IV.).

IV

Observers.—Thirty-five observers functioned in the experiment, all of whom were familiar with the important facts of color vision. Twenty-seven were members of elementary classes in psychology, five members of a class in experimental psychology and three were instructors in the department. Discrepancies in color judgment were avoided, so far as possible, by testing each observer's color vision by means of the Holmgren wools. Observers who could not pass the test satisfactorily were rejected.

Procedure.—The observer was seated facing the mixer directly in front and about one and a half feet from the shutter opening. The induction chamber, at the side of the observer, was so arranged that the position for induction could be attained by merely turning the head to the right. The distance from the shutter opening was kept constant throughout.

Before the experiment was started, instructions were given as to the duration of the primary stimulus (induction), the interval between induction and the opening of the shutter and the manner of reporting the color.

Method Without Induction.—The first judgment was made with the micrometer screw set at five eighths, the second at six eighths and so on, the registering point of the screw being moved one eighth of an inch after each judgment by means of the hand drive *C*. The portion of the revolving disc exposed at five eighths approximated black, but as the micrometer screw on which the small shield and shutter were attached was moved to the succeeding eighths, the degree of color increased with each exposure. The shutter exposure moved from a point near the center of the disc, where there was minimal saturation, toward greater saturation at the outer edge of the disc. Exposures of the same disc, with

increasing degrees of saturation, were continued until the color was recognized and confirmed by two immediately following judgments. If the judgment blue, for example, were made the two following judgments must be given as blue or the color was not considered as finally recognized. The limen of sensitivity without induction was first determined.

Method With Induction.—The instructions were repeated with reference to the duration of induction (primary stimulation), the interval between induction and the shutter opening, and the interval between closure of the shutter and the reappearance of the primary stimulus. The position for receiving the primary stimulus was assumed by the observer and the entire apparatus started as in previous experiments. The observer's attention was directed for a period of five seconds to the inducing color in the center of which was placed a small cross, as a fixation point. Two seconds intervened between the cessation of the primary stimulus and the appearance of the secondary stimulus through the shutter opening. This afforded ample opportunity for the observer to fixate the opening through the improvised light restriction hood. The revolving disc was exposed through the shutter opening for a period of one second. An interval of four seconds followed in which the observer reported the color as cognized and prepared for the second induction. The influence of one inducing color was determined in successive experiments for each of the four colors before employing a different inducing color. Experiments were stopped when evidence of fatigue appeared.

The order of presentation of the discs was changed to avoid as far as possible the factor of anticipation. Moreover, none of the observers were aware of the number of colors employed, for the reason that the substitution of the discs and the regulation of the degree of color exposed, were controlled from behind the shield (*T*, Plate I.).

V

Data.—Table I. gives one observer's judgments from the initial to the final micrometer readings for all the secondary

TABLE I

JUDGMENTS OF OBSERVER I

Inducing Colors (Primary Stimuli)	Color Disks (Secondary Stimuli)	Micrometer Readings in Eighths												
		5	6	7	8	9	10	11	12	13	14	15	16	17
None...	Blue....	Bk	Bk	Bk	Bl									
	Yellow..	Bk	Bk	Bk	Bk	Bk	Br	Br	DkG	DkOl	Ol	LtOl	LtOl	YG
	Green...	Bk	Bk	Bk	Bk	DkG	G							
	Red....	Bk	Bk	Bk	Bk	Bk	P	Br	Br	DkR	R			
Blue....	Blue....	Bk	Bk	Bk	Bk	Bl								
	Yellow..	Bk	Bk	Bk	OlG	OlG	OlG	OlG	OlG	LtOl	LtOl	YG	Y	
	Green...	Bk	Bk	Bk	Bk	DkG	G							
	Red....	Bk	Bk	Bk	Bk	Br	P	Br	Br	Br	DkR	R		
Yellow..	Blue....	Bk	Bk	Bk	Bl									
	Yellow..	Bk	Bk	DOl	DOl	Ol	Ol	Ol	Ol	Ol	YOl			
	Green...	Bk	DkG	G										
	Red....	Bk	Bk	Bk	Bk	Br	Br	Br	DkR	R				
Green...	Blue....	Bk	Bk	Bl										
	Yellow	Bk	Bk	Br	Bk	Bk	DkG	OlG	OlG	Ol	LtOl	YOl	Y	
	Green...	Bk	DkG	G										
	Red....	Bk	Bk	Bk	Br	P	RP	RBr	RBr	R				
Red....	Blue....	Bk	Bk	Bl										
	Yellow..	Bk	Bk	Bk	OlG	OlG	OlG	OlG	OlG	LtOl	LtOl	YG	Y	
	Green...	Bk	DkG	G										
	Red....	Bk	Bk	Bk	Bk	Br	Br	Br	Br	Br	Br	Br	Br	BrR

LtOl = light olive. The equivalents of the micrometer readings in degrees of color are found under Table XXIII.

stimuli with and without the influence of primary stimulation. A similar table was made for each of the remaining thirty-four observers but not incorporated separately in this study. The data in these thirty-five tables were rearranged as shown in Table II., except that Table II. contains only the judgments made on 'blue.' Tables III. to VII. inclusive summarize the data under Table II. The judgments on red, green and yellow are given in condensed form under Tables VIII. to XXII. inclusive.

The initial micrometer readings are the same for all colors except green which is three eighths. The final readings are seventeen, twenty, nineteen and eleven eighths for blue, yellow, red and green respectively. The degrees of color equivalent to these micrometer readings are found under Table XXIII.

In the condensed data of nearly all the tables there are

TABLE II

SUMMARY OF JUDGMENTS OF ALL OBSERVERS FOR THE BLUE DISK

Obs.		Micrometer Readings 5/8, Primary Stimuli					Micrometer Readings 6/8, Primary Stimuli					Micrometer Readings 7/8, Primary Stimuli				
		Bl	Y	Gr	R	N	Bl	Y	Gr	R	N	Bl	Y	Gr	R	N
1	Judgments	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bl	Bl	Bk
2	"	DkBl	Bk	DkBl	Bk	Bk	Bk	DkBl	Bl	DkBl	Bk	Bl	Bl	Bl	Bl	Bk
3	"	Bk	Bk	Bk	Bk	Br	PBl	DkBr	P	DkBr	P	DkP	P	P	Bl	Bl
4	"	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bl	Bk	Bk	Bk	DkV	Bl	Bk
5	"	Bk	Bk	Bk	Bk	Bk	BlBk	BlBk	Bk	Bk	Bk	BrBk	Bl	Bk	Bk	Bk
6	"	Bk	DkGr	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	DkBl	Bk	Bk	Bk
7	"	Bk	Gray	P	Bk	P	Bk	Gray	P	P	Bl	PBk	Bl	PBl	P	BlP
8	"	Bk	BrBk	BlBk	Bk	Bk	Gr	BlBk	BlBk	Bk	Bk	Bl	BlBk	BlBk	R	Bk
9	"	Bl	Bl	Bl	Bk	Bk	Bl	Bl	Bl	DkBl	Bk	Bl	Bl	Bl	Bl	BlBk
10	"	Bk	Bk	PBk	Bk	Bk	Bk	BlBk	BlBk	Bk	Bk	BlBk	BlBk	DkBl	PBk	Bk
11	"	P	Bk	DkP	Bk	Bk	P	DkP	DkP	Bk	Bk	Bl	P	DkP	DkP	Bk
12	"	BlBk	Bk	BkBl	Bk	Bk	BlBk	BlBk	DkBl	Bk	Bk	BlBk	Bl	Bl	BlBk	Bk
13	"	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk
14	"	Bk	Bk	Bk	BlBk	Bk	DkBl	DkBl	BlBk	Bl	Bk	Bl	Bl	Bl	Bl	R
15	"	Bk	PBk	Bk	Bk	Bk	BlBk	Bk	Bk	Bk	Bk	Bl	BlBk	BlBk	BlBk	Bl
16	"	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bl	Bl	Bk
17	"	DkGr	GrBk	Bk	Bk	DkGr	Bk	GrBk	BlBk	BrBl	DkGr	Bk	Bl	Bl	Bl	DkGr
18	"	Bk	DkBl	Bk	Bk	Bk	Bk	Bl	DkBl	DkGr	Bk	Bk	Bl	Bl	DkBl	Bk
19	"	Bk	PBr	RBr	Bk	Bk	Bk	PBr	RBr	Bk	Bk	RBk	PBr	RBr	PBk	Bk
20	"	BlBk	Bk	Bk	Bk	Bk	Bl	Bk	BlBk	Bl	Bk	Bl	BlBk	Bl	Bl	Bk
21	"	BlBk	Bk	Bl	PBk	Bk	Bl	Bk	Bl	BlBk	BlBk	Bl	Bk	Bl	Bl	Bl
22	"	BlBk	PBk	Bl	BlBk	Bk	Bl	BlBk	Bl	Bl	BlBk	Bl	Bl	Bl	Bl	Bl
23	"	Bk	BlBk	BlBk	Bk	R	Bk	Bl	Bl	Gr	R	BlBk	Bl	Bl	GrBk	Bk
24	"	DkBl	Bl	Bl	Bl	Bk	DkBl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	DkBl
25	"	DkBr	Bk	DkBr	DkR	Bk	Bk	DkP	DkP	DkBl	Br	DkP	BlP	DkBl	Bl	PBr
26	"	Bk	Bk	BlBk	BlBk	Bk	BlBk	Bk	P	Bk	Bk	Bl	Bk	Bl	Bl	Bk
27	"	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Gr	Bk
28	"	DkBl	BlBk	DkP	Bk	DkP	Bl	Bl	DkP	LBk	DkP	Bl	Bl	PR	BlBk	LtP
29	"	Bk	Bk	Bk	Bk	Bk	Bk	Bk	BlBk	BlBk	Bk	Bk	Bk	DkBl	DkBl	Bk
30	"	Bk	Bk	Bk	Bk	BlBk	Bk	Bk	Bk	Bk	BlBk	BlBk	Bk	Bk	BkBl	BkBk
31	"	PBk	Bk	Bk	Bk	GrBk	DkBl	BrBk	Bk	GrBk	GrBk	Bl	Bk	Bk	Bk	GrBk
32	"	BlBk	BlBk	Bk	Bk	Bk	BlBk	BlBk	Bk	BlBk	Bk	BlBk	BlBk	BlBk	BlBk	PBk
33	"	GrBk	PBk	Bk	Bk	BlBk	PBk	PBk	Bk	P	BlBk	GrBk	Bl	RBk	Bk	BlBk
34	"	Bk	Bk	Bk	BlBk	Bk	BlBk	Bl	DkBl	DkBl	DkBl	DkBl	Bl	Bl	Bl	Bl
35	"	Bl	Bk	V	Bl	Bk	Bl	Bk	V	Bl	Bk	Bl	Bl	V	Bl	BlBk

Abbreviations.—DkBl = Dark Blue; RBr = Red Brown; V = Violet; P = Purple.

SUMMARY OF JUDGMENTS OF ALL OBSERVERS FOR THE BLUE DISK

Obs.		Micrometer Readings 8/8, Primary Stimuli					Micrometer Readings 9/8, Primary Stimuli					Micrometer Readings 10/8, Primary Stimuli				
		Bl	Y	Gr	R	N	Bl	Y	Gr	R	N	Bl	Y	Gr	R	N
1	Judgments	Bk	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
2	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	DkBl
3	"	DkP	PBr	DkP	Bl	Bl	PBl	P	PBl	Bl	Bl	RP	DkBl	BlP	Bl	Bl
4	"	Bk	BlBk	V	Bl	Bk	Bk	PBk	DkBl	Bl	Bk	Bk	Bl	Bl	Bl	DkBl
5	"	BkBl	P	Bk	Bk	BlBk	BlBk	Bl	Bk	Bl	Bl	Bl	Bl	Bk	Bl	Bl
6	"	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
7	"	PBk	Bl	BlP	P	BlP	P	Bl	BlP	Bl	BlP	P	Bl	Bl	Bl	BlP
8	"	Br	BlBk	Bl	DkBr	Bl	Bk	BlBk	Bl	Bl	Bl	DkBl	Bl	Bl	Bl	Bl
9	"	Bl	Bl	Bl	Bk	BlBk	Bl	Bl	Bl	Bl	BlBk	Bl	Bl	Bl	Bl	Bl
10	"	BlBk	DkBl	Bl	BlBk	Bk	BlBk	DkBl	Bl	BlBk	BlBk	DkBl	Bl	Bl	DkBl	BlBk
11	"	Bl	LtP	Bl	P	P	Bl	Bl	Bl	Bl	PBl	Bl	Bl	Bl	Bl	Bl
12	"	Bl	Bl	Bl	BlBk	BlBk	Bl	Bl	Bl	Bl	BlBk	Bl	Bl	Bl	Bl	Bl
13	"	Bk	Bk	Bk	Bk	Bk	Bl	Bk	Bl	Bk	Bk	Bl	Bk	Bl	Bl	Bl
14	"	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
15	"	Bl	PBk	Bl	Bl	Bl	Bl	BlBk	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
16	"	Bk	Bl	Bk	Bl	Bk	BlBk	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bl
17	"	Bk	Bl	Bl	Bl	DkGr	Bl	Bl	Bl	Bl	DkGr	Bl	Bl	Bl	Bl	Bl
18	"	Bk	Bl	Bl	Bl	BlBk	Bl	Bl	Bl	Bl	DkBl	Bl	Bl	Bl	Bl	Bl
19	"	RBr	PBl	P	Bl	P	Bl	PBr	P	Bl	P	Bl	Bl	Bl	Bl	BlP
20	"	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
21	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
22	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
23	"	Bl	Bl	Bl	GrBk	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
24	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
25	"	BlP	DkBl	Bl	Bl	P	DkBl	Bl	Bl	Bl	P	Bl	Bl	Bl	Bl	Bl
26	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
27	"	Bk	Bk	Bk	Bk	Bk	Bk	Bk	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bk
28	"	Bl	Bl	BlBk	DkBl	BlP	Bl	Bl	DkBl	Bl	BlP	Bl	Bl	Bl	Bl	P
29	"	BlBk	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	BlBk	Bl	Bl	Bl	Bl	DkBl
30	"	BlBk	Bk	BlBk	BlBk	BlBk	DkBl	BlBk	BlBk	BlBk	BlBk	Bl	BlBk	DkBl	Bl	BlBk
31	"	Bl	PBr	GrBk	Bk	GrBk	Bl	DkBl	Bk	Bl	Bl	Bl	PBl	BlBk	Bk	Bk
32	"	Bl	BlBk	BlBk	nBl	BlBk	Bl	PBl	BlBk	Bk	Gr	Bl	Bl	Bl	Bl	Bl
33	"	Bl	Bl	PBk	DkP	Bl	Bl	Bl	P	DkP	Bl	Bl	Bl	Bl	PBl	Bl
34	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
35	"	Bl	Bl	Bl	Bl	DkBl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl

Abbreviations.—DkBl = Dark Blue; RBr = Red Brown; V = Violet; P = Purple.

SUMMARY OF JUDGMENTS OF ALL OBSERVERS FOR THE BLUE DISK

Obs.		Micrometer Readings 11/8, Primary Stimuli					Micrometer Readings 12/8, Primary Stimuli					Micrometer Readings 13/8, Primary Stimuli				
		Bl	Y	Gr	R	N	Bl	Y	Gr	R	N	Bl	Y	Gr	R	N
1	Judgments	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
2	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
3	"	DkBl	Bl	DkP	Bl	Bl	BlP	Bl	DkBl	Bl	Bl	Bl	Bl	PBl	Bl	Bl
4	"	DkV	DkBl	Bl	Bl	Bl	DkBl	VBk	Bl	Bl	Bl	Bl	DkBl	Bl	Bl	Bl
5	"	Bl	Bl	BlBk	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
6	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
7	"	BlP	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
8	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
9	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
10	"	Bl	Bl	Bl	Bl	DkBl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
11	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
12	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl
13	"	Bl	Bk	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
14	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
15	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
16	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
17	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
18	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
19	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
20	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
21	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
22	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
23	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
24	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
25	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
26	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
27	"	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bk
28	"	Bl	Bl	Bl	Bl	DkBl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
29	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
30	"	Bl	BlBk	P	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
31	"	Bl	PBl	DkBl	BlBk	Bk	Bl	Bl	Bl	BlBk	BlBk	Bl	Bl	Bl	Bl	BlBk
32	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
33	"	Bl	Bl	Bl	PBl	Bl	Bl	Bl	Bl	PBl	Bl	Bl	Bl	Bl	PBl	Bl
34	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
35	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl

Abbreviations.—DkBl = Dark Blue; RBr = Red Brown; V = Violet; P = Purple.

SUMMARY OF JUDGMENTS OF ALL OBSERVERS FOR THE BLUE DISK

Obs.		Micrometer Readings 14/8, Primary Stimuli					Micrometer Readings 15/8, Primary Stimuli					Micrometer Readings 16/8, Primary Stimuli				
		Bl	Y	Gr	R	N	Bl	Y	Gr	R	N	Bl	Y	Gr	R	N
1	Judgments	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
2	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
3	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
4	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
5	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
6	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
7	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
8	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
9	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
10	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
11	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
12	"	Bl	Bk	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
13	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
14	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
15	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
16	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
17	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
18	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
19	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
20	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
21	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
22	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
23	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
24	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
25	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
26	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
27	"	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bk	Bl	Bl	Bl	Bl	Bl
28	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
29	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
30	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
31	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
32	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
33	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
34	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl
35	"	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl	Bl

Abbreviations.—DkBl = Dark Blue; RBr = Red Brown; V = Violet; P = Purple.

certain judgments which involve two colors, or a color and a brightness, as the judgments YGr (yellow green), BlGr (blue green), DkBl (dark blue) and GrBk (greenish black). The variety of judgments was condensed according to the following directions:

1. When brightness was coupled to a color in a judgment the designated brightness was omitted from the record. Dark blue, for example, was recorded as blue.

2. When a judgment involved two colors of equal prominence that color was recorded which corresponded to the color on the disc. Purple blue was recorded as blue.

3. When a judgment involved two colors neither the one nor the other of which was the color on the disc that color was recorded which nearest resembled the disc. The judgment purple brown was recorded purple when the color on the disc was blue.

4. When a single color judgment, or a color judgment coupled with a brightness failed to correspond to the color on the disc the color judgment alone was recorded. The judgment dark brown on the green color disc was recorded as brown.

The 'Aggregation of Re-classified Judgments,' found in Tables III. to XXII. inclusive, constitutes a condensed grouping of all the data. Tables IV. to XXII. inclusive are abridgments of data analogous to that contained in the upper half of Table III.

Table XXIII. contains the degrees of color which were mixed with black for each micrometer reading. For green and red the amount of color was slightly less than for the blue and yellow for the 4/8 and 5/8 readings. In a comparison of the recognitive thresholds this gives a slight advantage or disadvantage to the former colors depending upon the nature of the primary stimulation.

The Curves.—Separate curves (ascending) for each color of the four discs under the five conditions of influence together with the curves (descending) for the accompanying 'black' judgments were plotted from the 'Aggregate Judgments' given in the tables. Ten curves were, therefore, drawn for

each color. To prevent crowding the curves two figures are devoted to each color, as Fig. 1 and Fig. 2 for the blue disk. The numerals along the ordinate axes indicate the

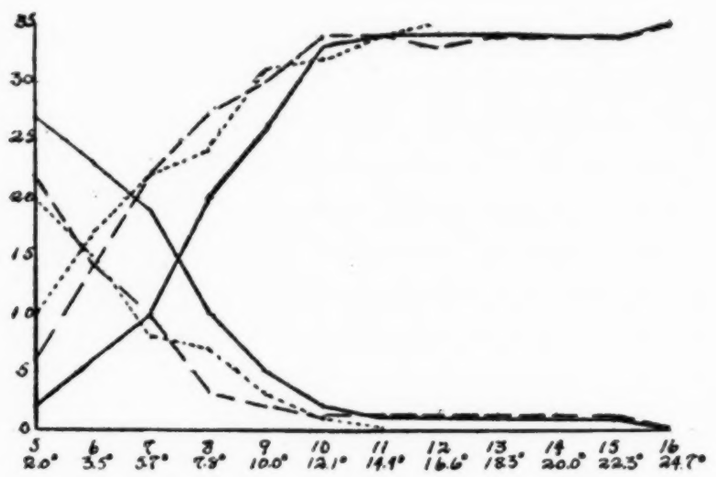

FIG. 1. Recognitive Limens for the Blue Disk.

distribution of the observers with reference to judgments of color for the different micrometer readings which are found along the abscissæ. Beneath these readings are the corresponding degrees of color.

The intersections of the 'color' curves with the 'black'

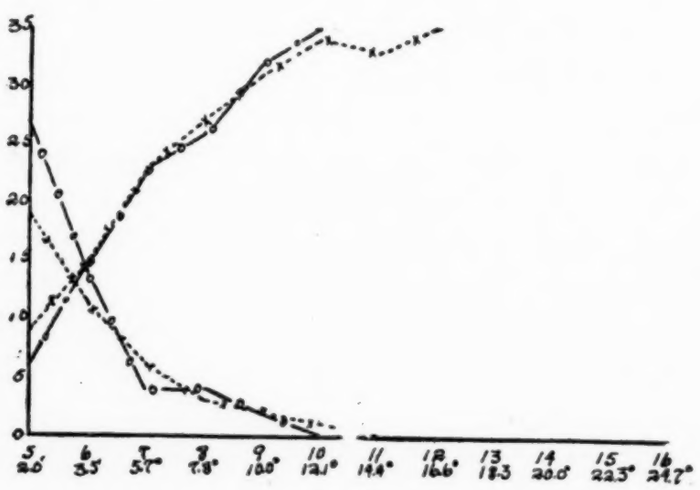

FIG. 2. Recognitive Limens for the Blue Disk. Points of intersection of curves = recognitive limens. Ascending curves = color judgments; descending curves = black judgments. —— = no influence; ..... = blue influence; —— —— = yellow influence; ...•... = green influence; ——o—— = red influence.

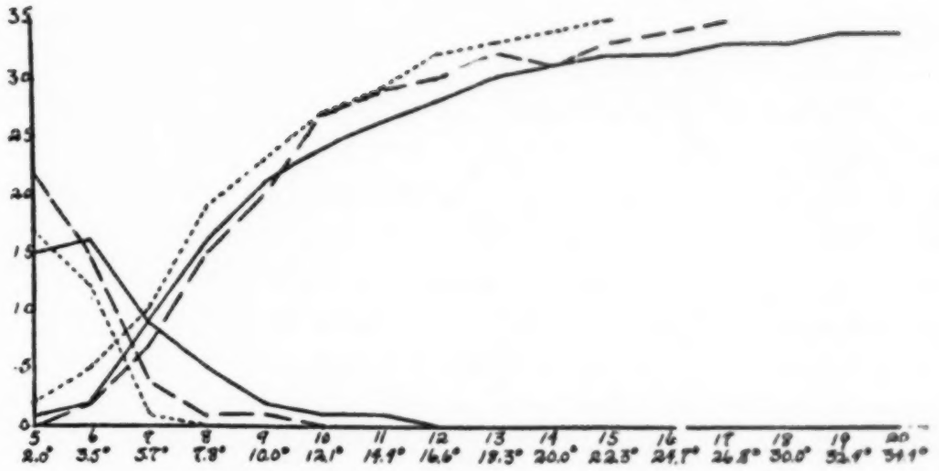

FIG. 3. Recognitive Limens for the Yellow Disk.

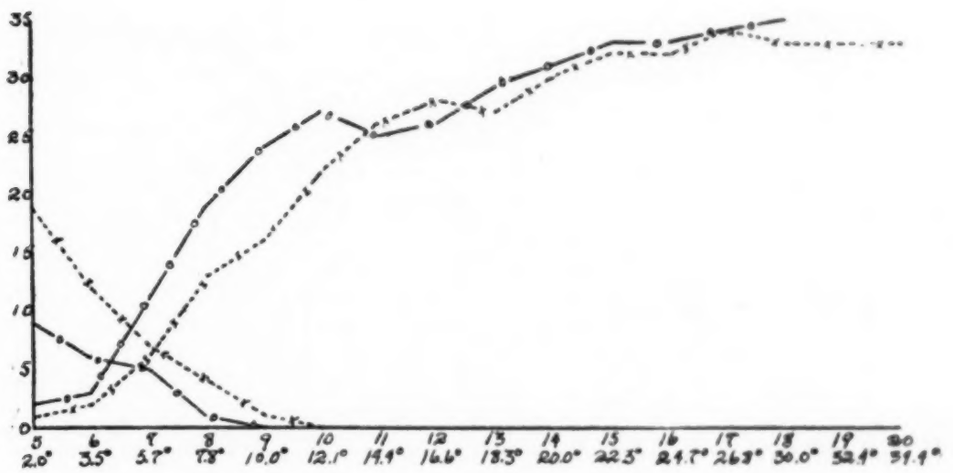

FIG. 4. Recognitive Limens for the Yellow Disk.

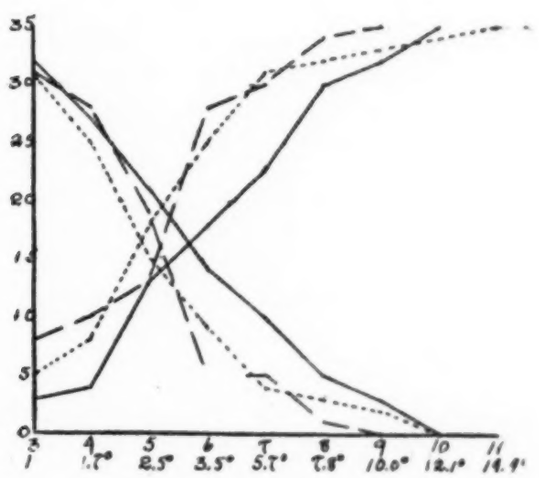

FIG. 5. Recognitive Limens for the Green Disk.

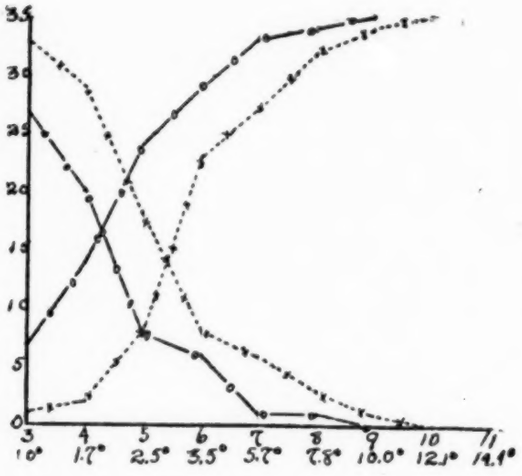

FIG. 6. Recognitive Limens for the Green Disk.

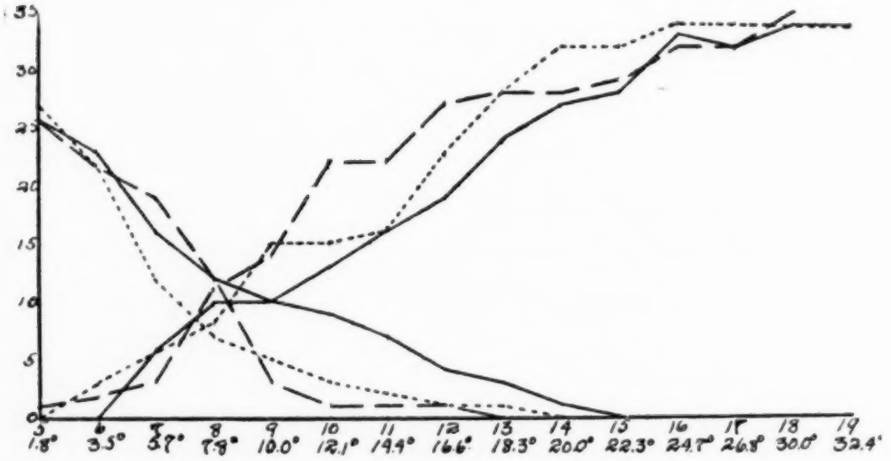

FIG. 7. Recognitive Limens for the Red Disk.

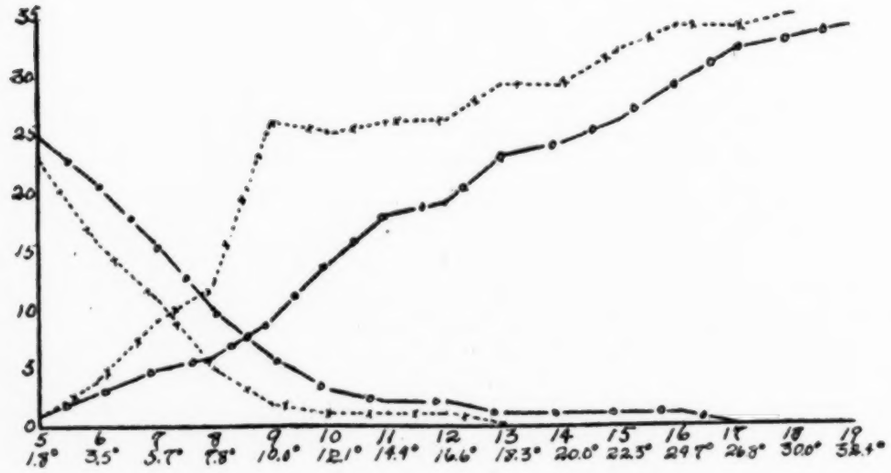

FIG. 8. Recognitive Limens for the Red Disk.

curves (Figs. 1 to 8), mark the recognitive limens for the various colors with and without the effects of primary stimulation. Since at the point of intersection the number of color judgments and black judgments is equal, this was termed the recognitive limen. The limens for the four colors of the color discs as influenced by the four inducing colors are arranged in an ascending series in Fig. 9. This sets forth in a diagrammatic way not only the amounts of color necessary for the recognition of a given color with different influences but also the relation of all the limens of one color with the limens of the remaining three colors.

TABLE III

COMBINED RESULTS OF ALL OBSERVERS FOR BLUE WITH NO INFLUENCE

Judgments	Micrometer Readings in Eighths											
	5	6	7	8	9	10	11	12	13	14	15	16
Bk	27	23	19	10	5	2	1	1	1	1	1	
DkBl		1	1	3	1	3	2					
BlBk	2	4	4	7	5	2						
Bl			4	8	17	26	31	34	34	34	34	35
P	1		1	3								
DkP	1	1										
GrBk	1	1	1	1								
DkGr	1	1	1	1	3							
Br	1	2										
BlP		1	1	2	3	2	1					
R	1	1	1									
PBr			1									
PBk			1									
Gr					1							

AGGREGATION OF RE-CLASSIFIED JUDGMENTS

Bk	27	23	19	10	5	2	1	1	1	1	1	
Bl	2	6	10	20	26	33	34	34	34	34	34	35
P	2	1	3	3								
G	2	2	2	2	4							
R	1	1	1									
Br	1	2										

Numerals under the micrometer readings signify the number of observers making a given judgment. 'With No Influence' means the absence of primary stimulation. The term 'Blue,' preceded by 'with No Influence,' refers to the color of the disk (secondary stimulus), on which judgments are made. Similar explanations apply to Tables IV. to XXII. inclusive. All judgments other than Bk and Bl, except as indicated above, are random judgments; they represent hazards and are not incorporated in the curves. Similar judgments are found in Tables IV. to XXII. inclusive.

TABLE IV

RESULTS OF ALL OBSERVERS FOR BLUE WITH BLUE INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths								
	5	6	7	8	9	10	11	12	13
Bk	20	15	8	7	3	1			
Bl	10	17	22	24	31	32	34	35	

TABLE V

RESULTS OF ALL OBSERVERS FOR BLUE WITH YELLOW INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths											
	5	6	7	8	9	10	11	12	13	14	15	16
Bk	22	14	10	3	2	1	1	1	1	1	1	
Bl	6	14	22	27	30	34	34	33	34	34	34	35

TABLE VI

RESULTS OF ALL OBSERVERS FOR BLUE WITH GREEN INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths									
	5	6	7	8	9	10	11	12	13	14
Bk	19	11	6	3	2	1				
Bl	9	15	23	27	31	34	33	35	35	35

TABLE VII

RESULTS OF ALL OBSERVERS FOR BLUE WITH RED INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths									
	5	6	7	8	9	10	11	12	13	14
Bk	27	14	4	4	2					
Bl	6	15	23	26	32	35	35	35	35	35

TABLE VIII

RESULTS OF ALL OBSERVERS FOR YELLOW WITH NO INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths															
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Bk	15	16	9	5	2	1	1									
Y	1	2	9	16	21	24	26	28	30	31	32	32	33	33	34	34

TABLE IX

RESULTS OF ALL OBSERVERS FOR YELLOW WITH BLUE INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths															
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Bk	17	12	1													
Y	2	5	10	19	23	27	29	32	33	34	35					

TABLE X

RESULTS OF ALL OBSERVERS FOR YELLOW WITH YELLOW INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths															
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Bk	22	15	4	1	1											
Y	0	2	7	15	20	27	28	30	32	31	33	34	35			

TABLE XI

RESULTS OF ALL OBSERVERS FOR YELLOW WITH GREEN INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths															
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Bk	19	12	7	4	1											
Y	1	2	6	13	16	22	26	28	27	30	32	32	34	33	33	33

TABLE XII

RESULTS OF ALL OBSERVERS FOR YELLOW WITH RED INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths															
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Bk	9	6	5	1												
Y	2	3	11	19	24	27	25	26	29	31	33	33	34	35		

TABLE XIII

RESULTS OF ALL OBSERVERS FOR GREEN WITH NO INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths							
	3	4	5	6	7	8	9	10
Bk	32	27	21	14	10	5	3	
Gr	3	4	13	18	23	30	32	35

TABLE XIV

RESULTS OF ALL OBSERVERS FOR GREEN WITH BLUE INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths								
	3	4	5	6	7	8	9	10	11
Bk	29	25	15	9	4	3	2	1	
Gr	5	8	18	25	31	32	33	34	35

TABLE XV

RESULTS OF ALL OBSERVERS FOR GREEN WITH YELLOW INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths							
	3	4	5	6	7	8	9	10
Bk	31	28	19	5	5	1		
Gr	3	5	13	28	30	34	35	

TABLE XVI

RESULTS OF ALL OBSERVERS FOR GREEN WITH GREEN INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths								
	3	4	5	6	7	8	9	10	11
Bk	33	29	18	8	6	3	1		
Gr	1	1	8	23	27	32	34	35	

TABLE XVII

RESULTS OF ALL OBSERVERS FOR GREEN WITH RED INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths							
	3	4	5	6	7	8	9	10
Bk	27	20	8	6	1	1		
Gr	7	14	24	29	33	34	35	

TABLE XVIII

RESULTS OF ALL OBSERVERS FOR RED WITH NO INFLUENCE

Aggregation of Re-classified Judgments

Judg-ments	Micrometer Readings in Eighths														
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Bk	26	23	16	12	10	9	7	4	3	1					
R	0	0	6	10	10	13	16	19	24	27	28	33	32	34	34

TABLE XIX

RESULTS OF ALL OBSERVERS FOR RED WITH BLUE INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths														
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Bk.....	27	22	12	7	5	3	2	1	1						
R.....	0	3	6	8	15	15	16	23	28	32	32	34	34	34	34

TABLE XX

RESULTS OF ALL OBSERVERS FOR RED WITH YELLOW INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths														
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Bk.....	26	22	19	12	3	1	1	1							
R.....	1	2	3	11	14	22	22	27	28	28	29	32	32	35	

TABLE XXI

RESULTS OF ALL OBSERVERS FOR RED WITH GREEN INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths														
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Bk.....	23	16	11	5	2	1	1	1							
R.....	1	4	9	12	26	25	26	26	29	29	32	34	34	35	

TABLE XXII

RESULTS OF ALL OBSERVERS FOR RED WITH RED INFLUENCE

Aggregation of Re-classified Judgments

Judgments	Micrometer Readings in Eighths														
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Bk.....	25	21	16	10	6	3	2	2	1	1	1	1			
R.....	1	3	5	6	9	14	18	19	23	24	26	29	32	33	34

VI

Results.—Figs. 10 and 11 show the recognitive limens in condensed form for the four primary colors with and without the influence of primary stimulation; they also throw into clear relief the quantitative relations of the various limens. As already indicated these limens are the intersecting points of the curves grouped in Figs. 1 to 8 inclusive.

TABLE XXIII

DEGREES OF COLOR COMMENSURATE WITH MICROMETER READINGS

Eighths	Blue	Color Disks Yellow	Green	Red
4	1.2	1.2	1.7	0.7
5	2.0	2.0	2.5	1.8
6	3.5	3.5	3.5	3.5
7	5.7	5.7	5.7	5.7
8	7.8	7.8	7.8	7.8
9	10.0	10.0	10.0	10.0
10	12.1	12.1	12.1	12.1
11	14.4	14.4	14.4	14.4
12	16.6	16.6	16.6	16.6
13	18.3	18.3	18.3	18.3
14	20.0	20.0	20.0	20.0
15	22.3	22.3	22.3	22.3
16	24.7	24.7	24.7	24.7
17	26.8	26.8	26.8	26.8
18	30.0	30.0	30.0	30.0
19	32.4	32.4	32.4	32.4
20	34.4	34.4	34.4	34.4

Reference to Figs. 10 and 11 indicates the following results:

1. The recognitive limens for blue (7.5–6.7°),[1] red (9–10°) and green (5.4–2.9°) 'without influence' are higher than any other limens for these colors when 'influenced by the after-effects of primary stimuli.'

2. The five limens for blue, red and green form identical series, as to sequence, of decreasing magnitudes. These series conform to the following order of primary stimulations: red, yellow, blue and green. While the relative values of the limens in these three series remain the same, their absolute values vary. For example, the limen for blue, determined after stimulation for red, is 6.1–3.7° while for red under the same conditions the limen is 8.6–9.10° and for green 4.3–1.9°. The maximum and minimum limens for green, blue and red under identical conditions with respect to previous stimulation are 5.7–3.3°; 4.3–1.9° (green), 7.5–6.7°; 5.7–3° (blue) and 9–10°; 7.2–6.1° (red). The differences of these maxima and minima in the direction of red are 3.3–6.7°; 2.9–4.1° and 1.5–3.3°; 1.5–3.1°.

3. The sequence of limens for yellow varies somewhat from those for blue, green and red. In the case of yellow two of

[1] 7.5–6.7° = micrometer readings (7.5 eighths) and degrees of color (6.7°).

the limens fall together, *i. e.*, the limen for yellow without the after-effects of primary stimulation and the limen with the after-effects of previous stimulation with green is 7.1–5.9°. The sequence of limens for yellow following the order of

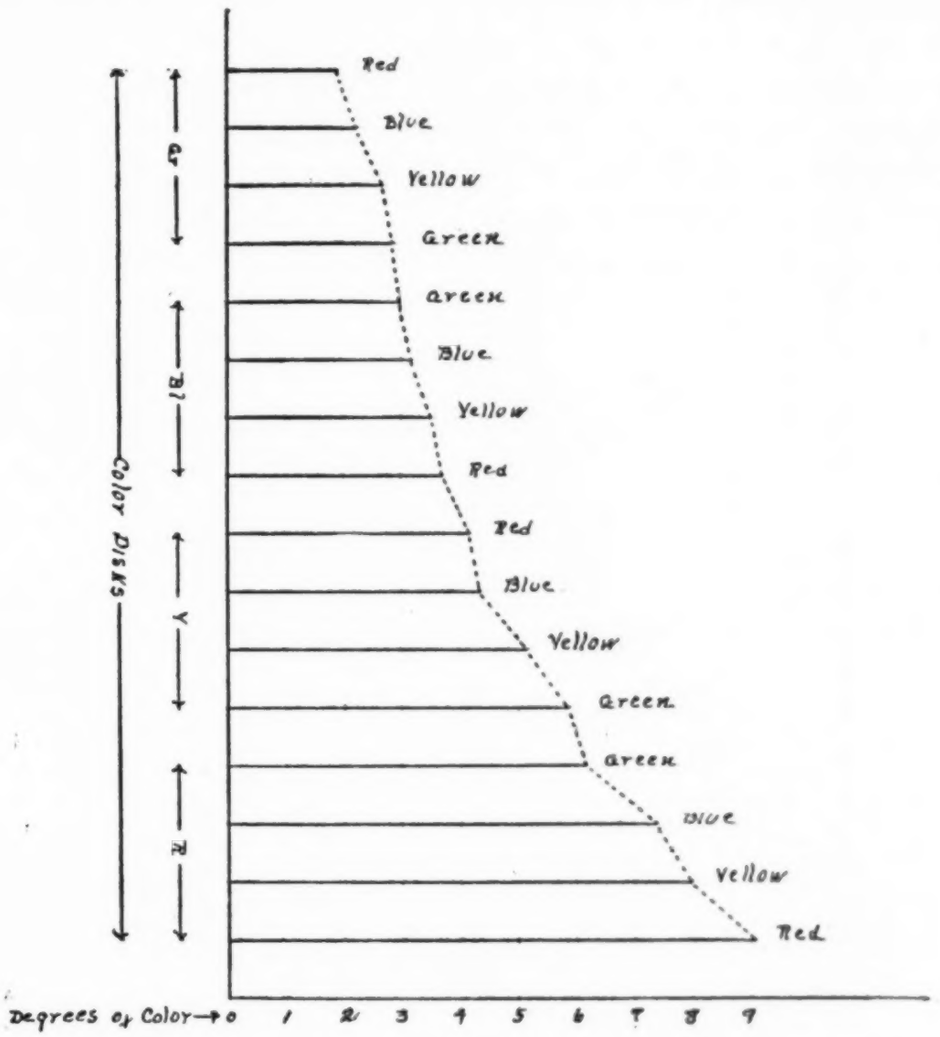

FIG. 9. Quantitative relationship of the various limens for the secondary stimuli (color disks). The terminal readings of the various abscissæ indicate the limens of color sensitivity for the four secondary stimuli as influenced by the different inducing colors. The names of the colors at the ends of the lines indicate primary stimuli (inducing colors).

primary stimulations as shown in the graph (Fig. 11) is: Green (none), yellow, blue and red.

4. The limens for red corresponding to the limens for the three other primary colors are throughout the highest; those

for green are throughout the lowest; while the corresponding limens for blue and yellow fall between the two extremes of the limens for red and green. Fig. 9 represents the relative positions graphically. It will be noted, and this is interesting, that the antagonistic colors red and green have throughout

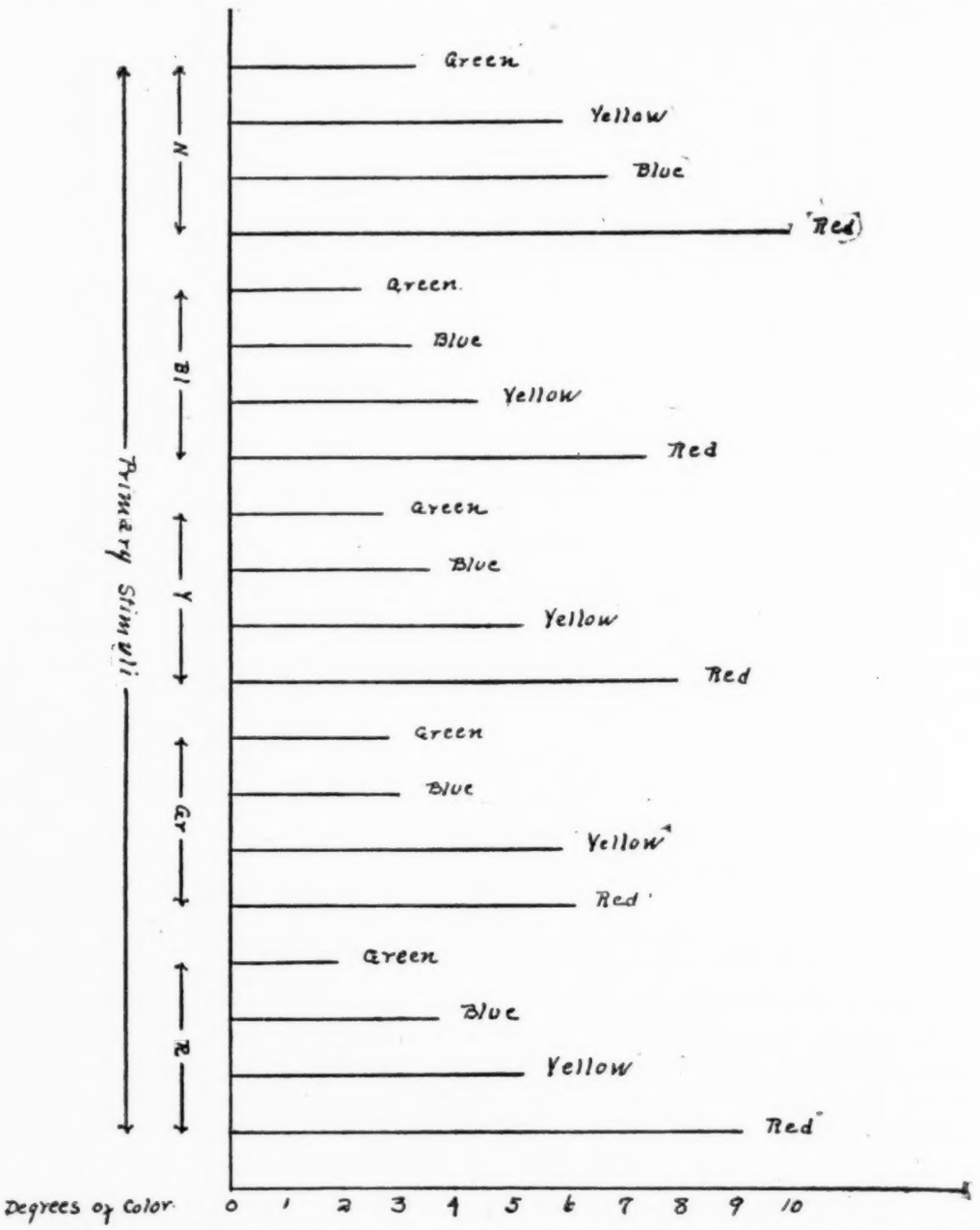

FIG. 10. Limens of sensitivity with and without induction. Color names at the ends of lines indicate the secondary stimuli (color disks). The terminal readings of the various abscissæ indicate the limens of color sensitivity for the four primary colors as influenced by the different primary stimuli.

the highest and the lowest limens respectively while the limens for the complementary colors blue and yellow fall between these two extremes.

Conclusions.—The duration and character of the after-effects of stimulation are so varied and elusive, the exact composition of color papers so difficult of precise determination, the condition of the retina and the composition of incandescent lights so variable and the influence of eye-movements, practice and fatigue so important that deductions from the data should be made with the greatest care.

1. When the after-effects of a primary stimulus is similar to the color of the disc the limen is the lowest of the

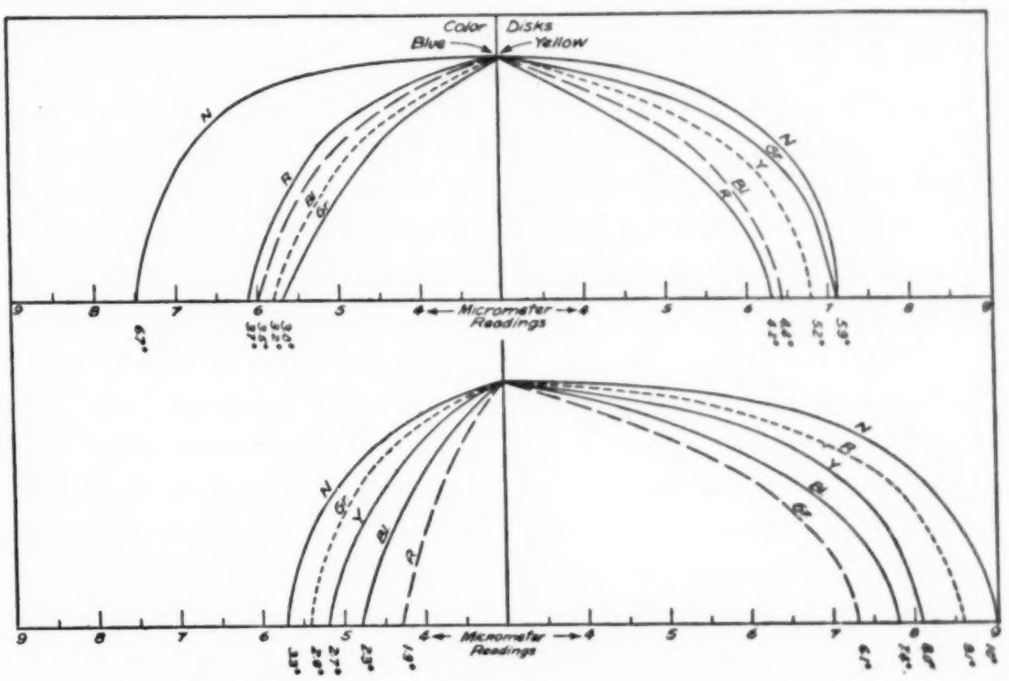

FIG. 11. Recognitive limens as given in micrometer readings and degrees of color. Color abbreviations on curved lines indicate the colors of the primary stimuli. *N* = primary stimulus lacking. ...., indicate primary stimuli followed by after-images complementary to colors on vertical line. —— ——, ——, indicate primary stimuli complementary to colors on vertical line. The points on the vertical line were arbitrarily chosen.

five limens for this color. This is true for the green, yellow and red color discs employed in this experiment. In these cases the limens are 4.3–1.9°; 6.4–4.4° and 7.2–6.1° respectively. An exception to this conclusion is found in the case of the blue disc in which case the lowest limen is connected with

green rather than a primary stimulation of yellow as we might expect. The explanation is probably found in the difference of brightness values of the after-effects of blue and green stimulations, the effects of the latter in this respect being greater. The difference between these two limens is, however, very slight, being .3/8 micrometer reading or .2° of color. In this connection it is interesting to note that Parsons[1] observed: "If the secondary stimulation is the complementary color of the primary, the resulting sensation is that of an extremely saturated complementary color." The lowest limens for the green, yellow and red colors are cases in which the primary stimuli are complementary colors, *i. e.*, red for the bluish green, blue for the yellow and bluish green for the red. The after-images for these primary stimuli would, therefore, be same-colored as the colors on the discs, and tend to raise the saturation of these colors. It is altogether likely that the saturation of the after-image exceeds that of the color on the discs so that the total effect is a compromise between the degree of color with reference to its saturation and the after-image.

With reference to the saturation of a spectral color Parsons[1] observes: "It may be far more saturated than any spectral color so that it is impossible to obtain a comparison light which will match it." The investigations of v. Kries[2] and his students on the effect of the after-images on color matches are instructive in this connection. He found that a yellow paled or became more saturated according to whether the after-image was blue or yellow. It appears that we may probably conclude that the lowest limens for green, yellow and red are traceable to an increase in saturation due to the after-effects of the primary stimuli complementary to these colors.

2. When the primary stimulations are not complementary to the secondary stimulations the influence of the effects of primary stimuli upon the recognitive limens of the secondary stimuli is more difficult to trace. From Fig. 10 it is seen that

[1] Parsons, *op. cit.*, p. 109.

[2] Citation from Parsons' 'Introduction to Color Vision,' p. 105.

the limens for the colors here investigated are, in eleven cases out of twelve, lower when the primary stimuli are not the complementary of the secondary stimuli. The exception is the limen for yellow when the primary stimulus is green. This limen falls together with the limen of yellow when uninfluenced by primary stimulation.

Theoretically, and perhaps upon the basis of the work of v. Kries (quoted above), we might expect a higher limen for a given color when the after-image of a primary stimulus is complementary to this color. For example, a blue after-image pales a yellow color. If the degree of saturation is a determinant of color recognition then we should expect higher limens for colors when influenced by after-images which are complementary (antagonistic) than when primary stimulations are lacking. Our results are not, in the main, in accord with this expectation. Moreover, our color limens are (except for yellow, in which case the limen is equal) lower when influenced by after-images which are neither complementary to nor same-colored as the color discs than when primary stimulations are entirely lacking.

APPARATUS AND EXPERIMENTS FOR THE INTRODUCTORY COURSE

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I. A Combined Tilting Board and Rotation Table

Apparatus.—This is a modification of the two pieces of apparatus described in Sanford's 'Course.' The board used in the combination is 6 ft. 4 in. long, 2 ft. wide, and $1\frac{1}{2}$ in. thick. At each end a piece of $3\frac{1}{2} \times 1\frac{1}{2}$ inch pine is nailed on the upper side to serve as a brace as well as to prevent the subject from slipping during the tilting experiment. Near each end notches are cut in the side to serve as grooves for the straps which hold the subject in position. Beneath the center of the board is fastened the swivel screw from an office chair for the horizontal rotation, and across the middle of the board is a steel axle about which the board rotates vertically in the tilting experiment. This axis projects about 3 inches beyond each edge of the board.

The figure (Fig. 1) shows the apparatus used as a tilting board with a subject strapped on as in an experiment. One support for the board, in shape of an A, is permanently fixed to the wall and is made of yellow pine. The other support, of 4×3 in. white pine, is a post which extends from floor to ceiling and is removed when not in use. A hole in the ceiling slightly larger than this upright allows it to just slip through and the fit is then made snug by V-shaped wedges. On the bottom of the upright is a small iron projection which fits into a hole in the floor. The bearings for the axis of vertical rotation are Y-shaped and are made of steel. These bearings are securely fastened to the supports just high enough to allow about six inches clearance from the floor when the board stands vertical. Thus the subject may be rotated through all angular positions from the natural upright position to a position in which his head is straight down. An angular

scale with a plumb bob is attached to the board so that all angular positions are read directly.

Procedure.—In the introductory course the tilting experiment is conducted as follows: The subject, with eyes closed, is strapped to the board; one experimenter holds each end of the board, and usually a third reads and records the judgments. (*a*) The experimenters slowly rock the board up

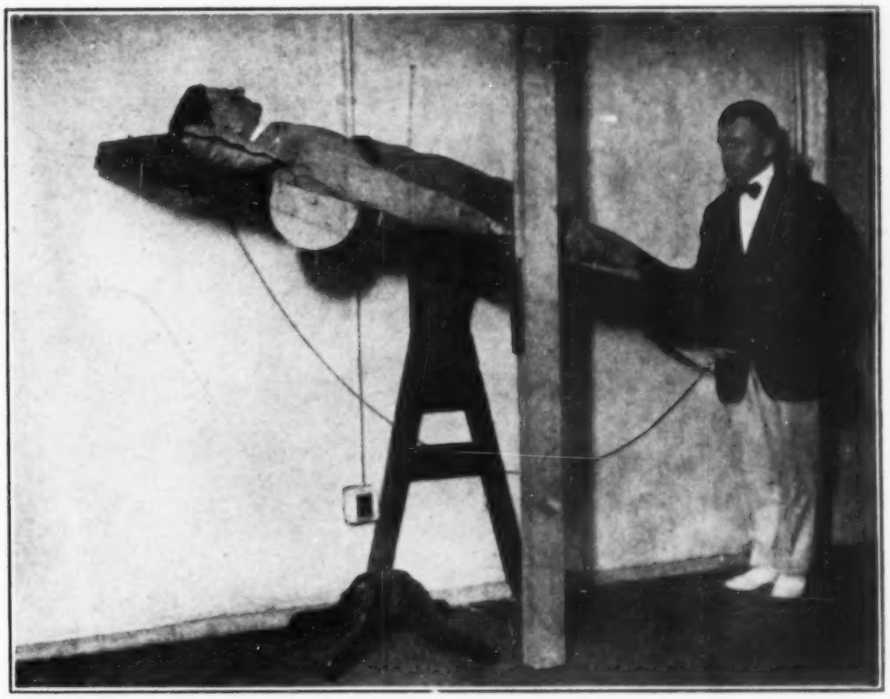

FIG. 1.

and down a few times and the subject then directs the movement until he judges his body parallel to the floor. The scale reading is recorded in a column headed 'Level.' (*b*) The board is then slowly rotated so that the subject's head rises; the subject directs the movement until he judges himself to be 'half-way up' and this is recorded under + 45°. (*c*) The rotation is continued until the subject judges himself perpendicular to the floor. Recorded under + 90°. (*d*, *e*) The direction of rotation is now reversed and the subject again indicates the 'half-way' and 'level.' (*f*, *g*, *h*, *i*) Continuing the rotation, the subject's head is moved down and he indicates the − 45° and − 90° points. Reverse the

movement and determine $-45°$ and 'Level.' (These last four readings should be taken as rapidly as possible.)

The subject works out the deviation for each position, and in this way learns to what extent one is ordinarily dependent on vision in determining the position of the body.

To use the board as a rotation table for horizontal rotation it is easily lifted from the supports and screwed into the base of an office chair by means of the swivel screw. It is then free to rotate horizontally and is operated by a stout cord fastened to each end of the board.

In the introductory course the rotation table is used as a class demonstration. The subject, eyes closed, lies on the table with his head on a partly inflated air pillow. When the subject detects motion he indicates the direction by raising the hand on the side toward which his head is moving and keeps his hand raised as long as the motion is felt. (*a*) The experimenter at first rotates the table very slowly and the remainder of the class observe that no motion is detected by the subject. (*b*) The rate of motion is increased by the experimenter and then rather suddenly the table is stopped. The subject lowers one hand and raises the other, indicating an apparent rotation in the opposite direction.

(*c*) The experimenter again rotates the table at a uniform rate for several complete revolutions and watches the subject's hands. Then slowly the rate of motion is decreased. Fatigue causes an apparent cessation of movement as shown by the subject dropping his hand, and often a reversal will be indicated on decreasing the rate of motion.

(*d*) Next the subject turns his head so as to rest on one ear and the experimenter rotates the board at a medium velocity. As soon as the subject indicates that the motion has apparently stopped he is directed to turn his head quickly to the other side and note the effect. The direction of stimulation in the fatigued organs is reversed and the sense of motion is taken up again in the same objective direction.

Each student takes notes on his observation of other subjects, and records his own sensations when acting as subject.

II. A Size-Weight Illusion Experiment

Numerous size-weight experiments have been offered with varying degrees of success, but they often involve special apparatus. The apparatus used in this experiment (Fig. 2) can be duplicated in any laboratory without extra expense. If any object here mentioned is not available it can easily be replaced by some similar article.

Seventeen articles are included in the experiment; this

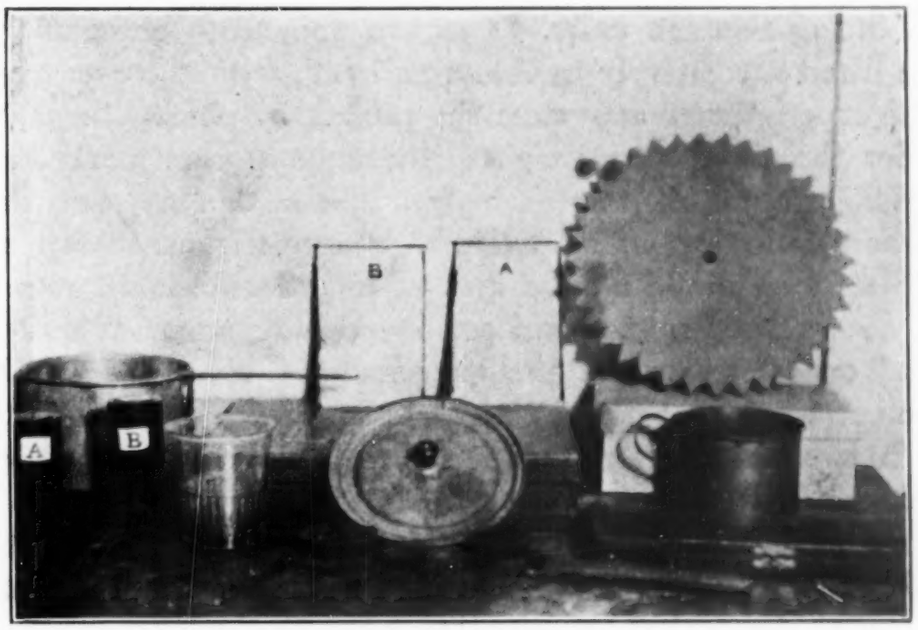

Fig. 2.

number may be increased or diminished, as the crucial point is the various classes of objects used rather than their number. The articles may be classed as follows: I. Compact solid, II. flat, III. long slender, IV. cylindrical, V. hollow closed, and VI. hollow open.

Articles Used	Weight, Grams	Class
1. Ordinary sauce pan with handle	381	VI
2. Jastrow cylinder *A*, weighted with shot and cotton	350	IV
3. Milton Bradley pseudoptic box empty	255	V
4. Esthesiometer (Verdin) box	250	V
5. Cold chisel	241	I
6. 200-gram weight	200	I
7. Glass tumbler	200	VI
8. Ruler, anthropometric	140	III

9. Buzz-saw disk of heavy cardboard	140	II
10. Tin cup	101	VI
11. 100-gram weight	100	I
12. Jastrow cylinder *B*	100	IV
13. Sanford envelope *A*	100	II
14. Pasteboard box, Library Bureau	88	V
15. Saucepan lid	85	II
16. Sanford envelope *B*	82	II
17. 50-gram weight	50	I

Procedure.—The articles are distributed at random on a table and the subject is told to arrange them in order of weight by lifting them in pairs. The two objects to be compared are lifted successively in the same hand, with the eyes open. The experimenter may start the subject by placing in proper order the three scale weights (the only objects marked) as an illustration of the problem. These weights will then serve as starting points for further comparisons. After the subject has placed all the articles in order he is allowed to go over the entire set and revise his judgment. When the final order is reached the experimenter gives the subject the correct weight of each article. The subject is instructed to compare his arrangement of the articles with the correct order and to note the relative displacement of each class of articles to right or left, as well as the displacement of the individual articles. No subject acts as experimenter or sees the work of another subject until after he himself has served as subject.

The experiment has been given in the Princeton Laboratory for a number of years and the records of 114 subjects have been kept. In no case has the illusion been absent, while in practically all cases it has been quite pronounced, even though the subject knew the nature of the experiment beforehand. 39 out of the 45 subjects using the articles as here described placed cylinder *A* at the heavy end, while the saucepan was displaced from one to eight places toward the light end and was correctly placed by only three subjects. The pasteboard box, No. 14 in weight order, was placed at the light end by 37 out of 45 subjects and the 50-gram weight was correctly placed by only two subjects. A typical arrangement of the articles is: 2, 5, 6, 1, 11, 9, 13, 4, 17, 6, 16, 10,

15, 8, 12, 3, 14. The individual result in which the illusion was most markedly absent is: 1, 2, 4, 3, 5, 8, 9, 7, 6, 10, 15, 11, 13, 14, 12, 16, 17.

At the same laboratory period the subjects are also given Whipple's Suggestion Blocks.[1]

[1] Whipple's 'Manual of Mental and Physical Tests,' Test 40. The reference also contains a bibliography of references on size-weight illusions.